



US008120850B2

(12) **United States Patent**
Uchida et al.

(10) **Patent No.:** **US 8,120,850 B2**
(45) **Date of Patent:** ***Feb. 21, 2012**

(54) **ZOOM LENS SYSTEM, INTERCHANGEABLE LENS APPARATUS AND CAMERA SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 35 days.

This patent is subject to a terminal disclaimer.

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(21) Appl. No.: **12/695,309**

(22) Filed: **Jan. 28, 2010**

(65) **Prior Publication Data**

US 2010/0195207 A1 Aug. 5, 2010

(30) **Foreign Application Priority Data**

Jan. 30, 2009 (JP) 2009-020091

(51) **Int. Cl.**

G02B 27/64 (2006.01)

G02B 15/14 (2006.01)

(52) **U.S. Cl.** **359/557**; 359/554; 359/686; 359/688

(58) **Field of Classification Search** 359/554-557, 359/676-690

See application file for complete search history.

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Primary Examiner — Thong Nguyen

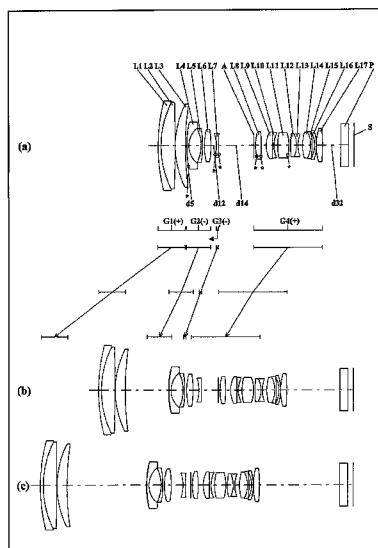
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(57)

ABSTRACT

Provided is a zoom lens system including a compact focusing lens unit and having a suppressed change in image magnification at the time of movement of the focusing lens unit. The zoom lens system of the present invention, in order from an object side to an image side, includes a first lens unit G1 having positive optical power, a second lens unit G2 having negative optical power, a third lens unit G3 having negative optical power, and a fourth lens unit G4 having positive optical power. At the time of zooming, at least the first lens unit G1 moves from a wide-angle limit to a telephoto limit. The fourth lens unit G4 includes a first sub lens unit having positive optical power and a second sub lens unit having negative optical power, the second sub lens unit being arranged at the image side relative to the first sub lens unit. At the time of compensating image blur caused by vibration applied to the zoom lens system, the first sub lens unit or the second sub lens unit moves in a direction perpendicular to the optical axis.

13 Claims, 16 Drawing Sheets



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FIG. 1

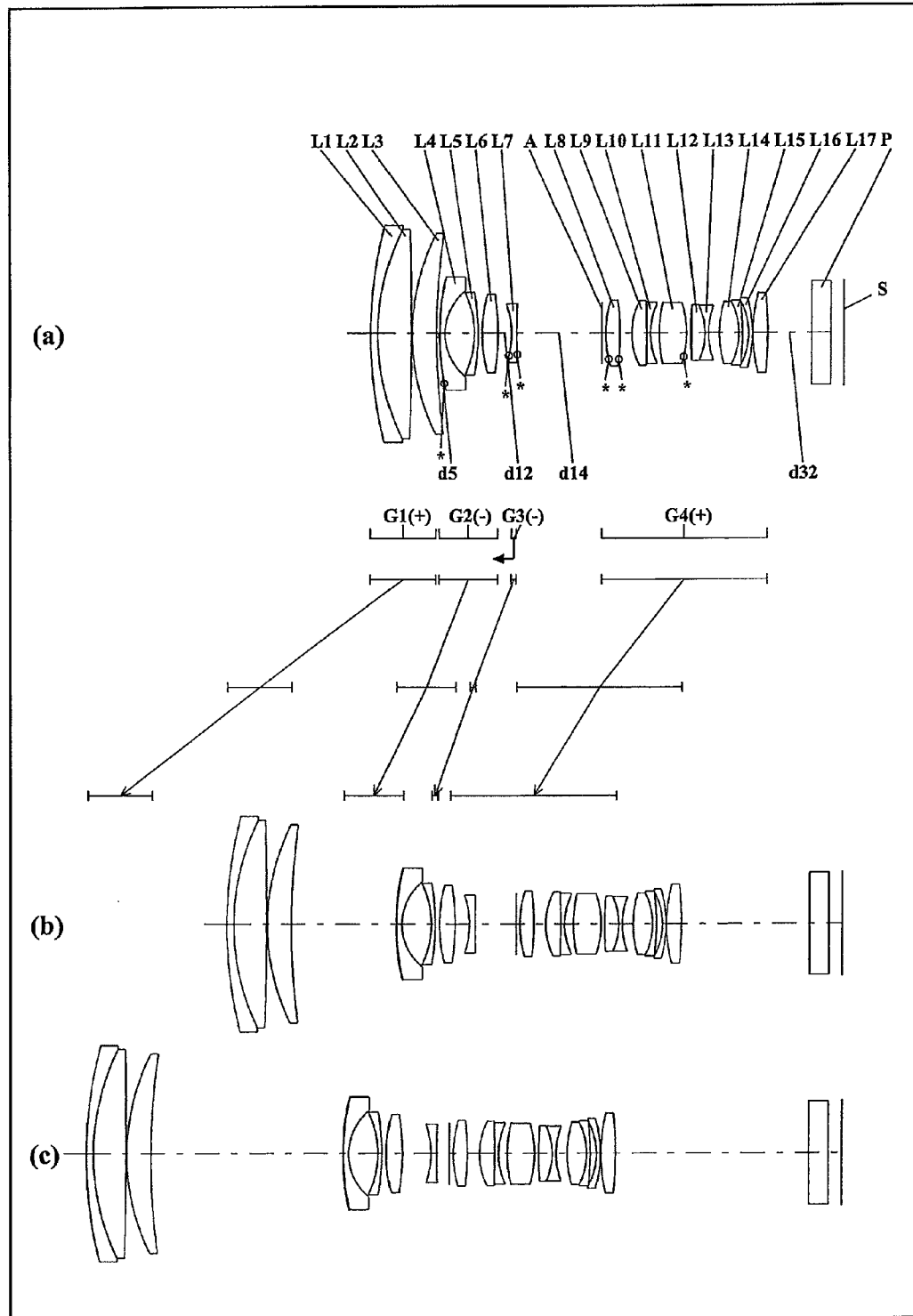


FIG. 2

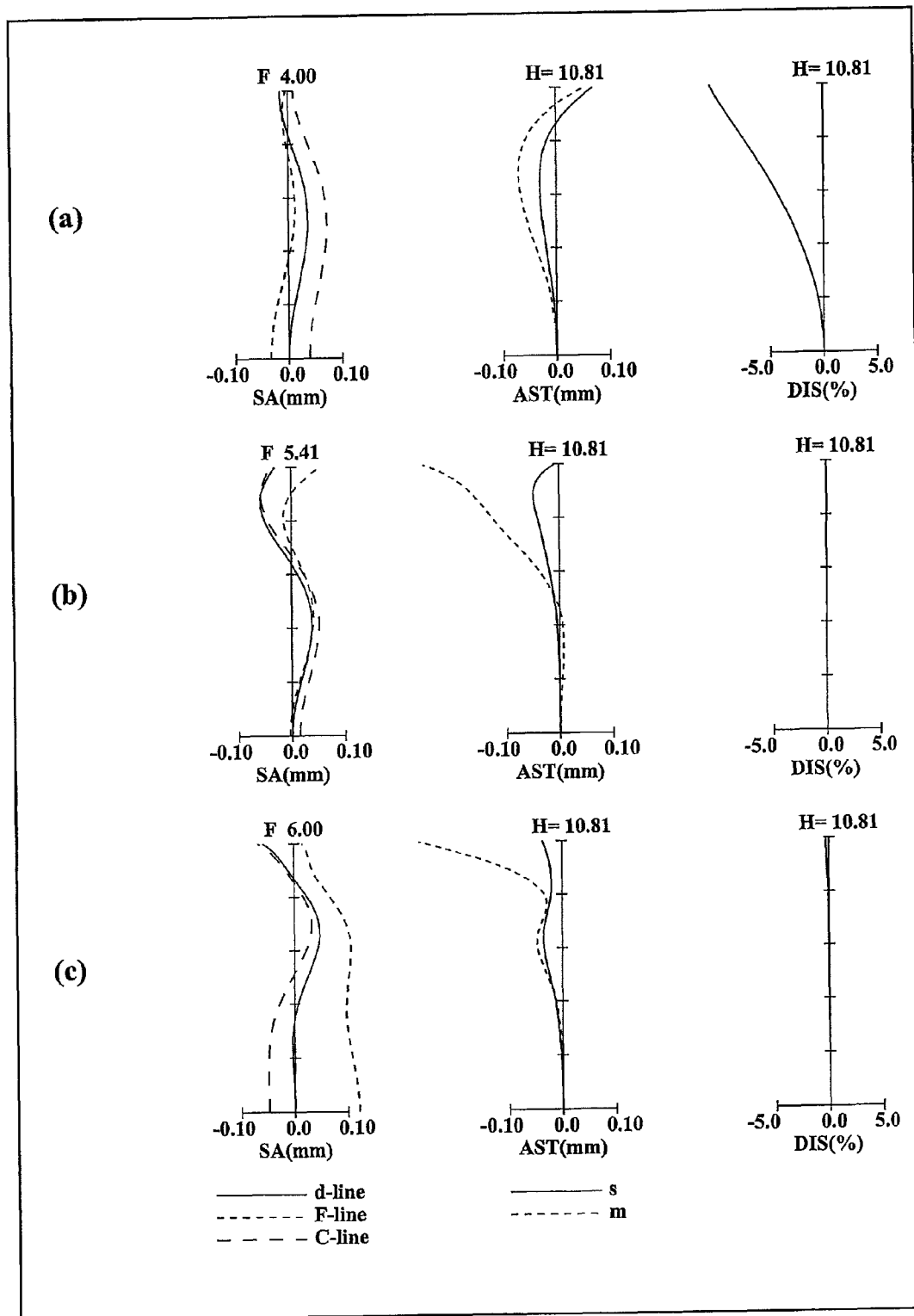


FIG. 3

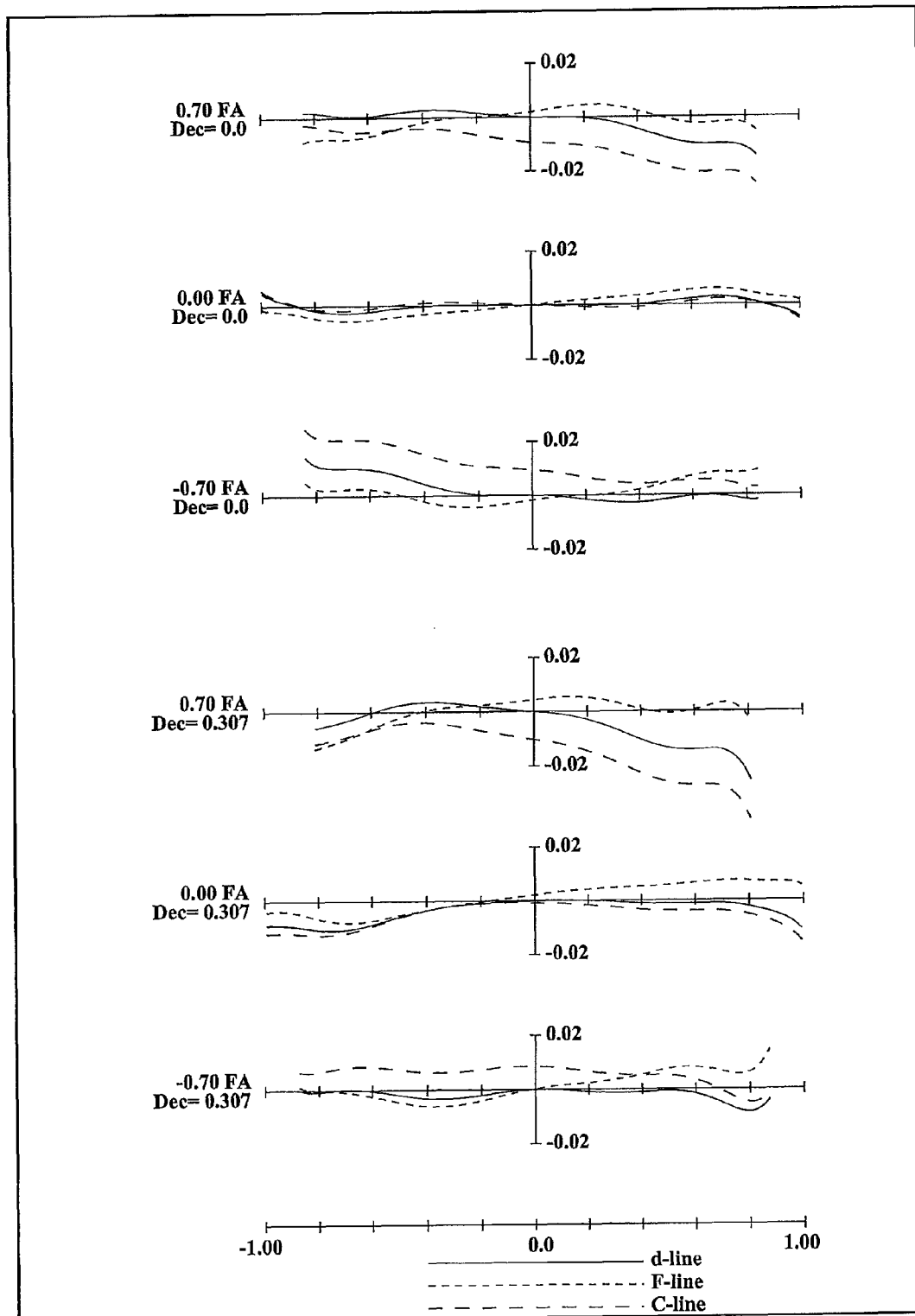


FIG. 4

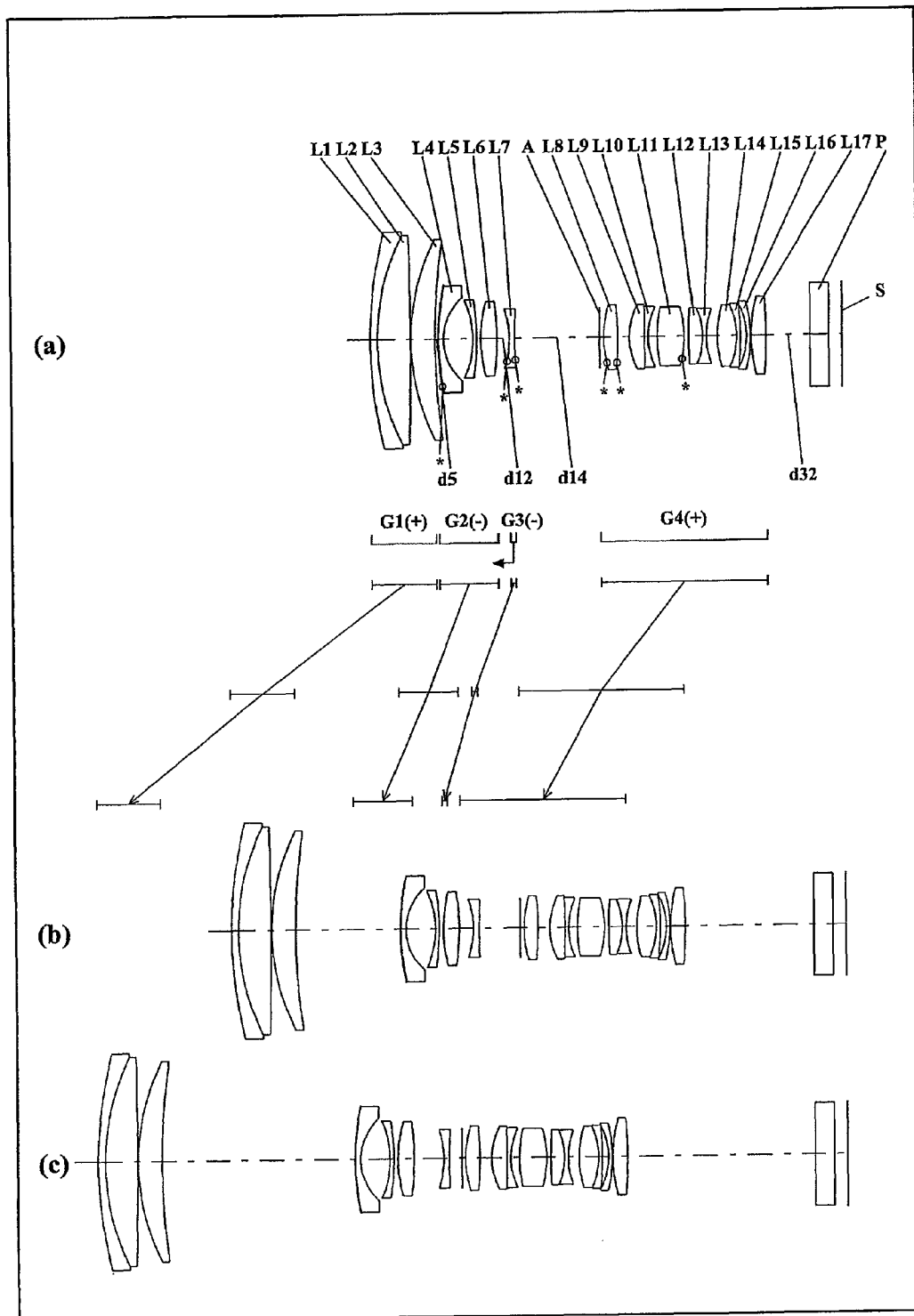


FIG. 5

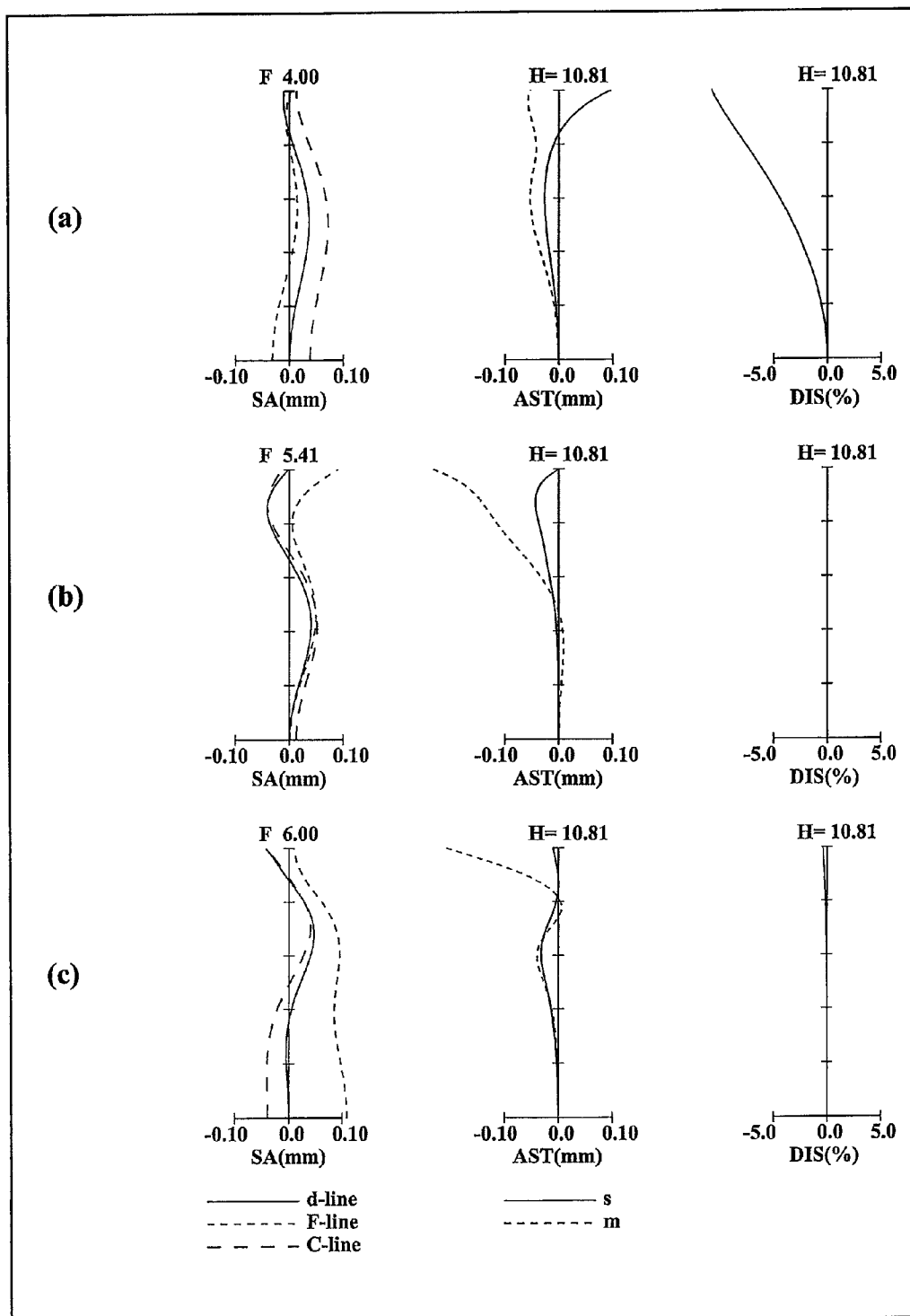


FIG. 6

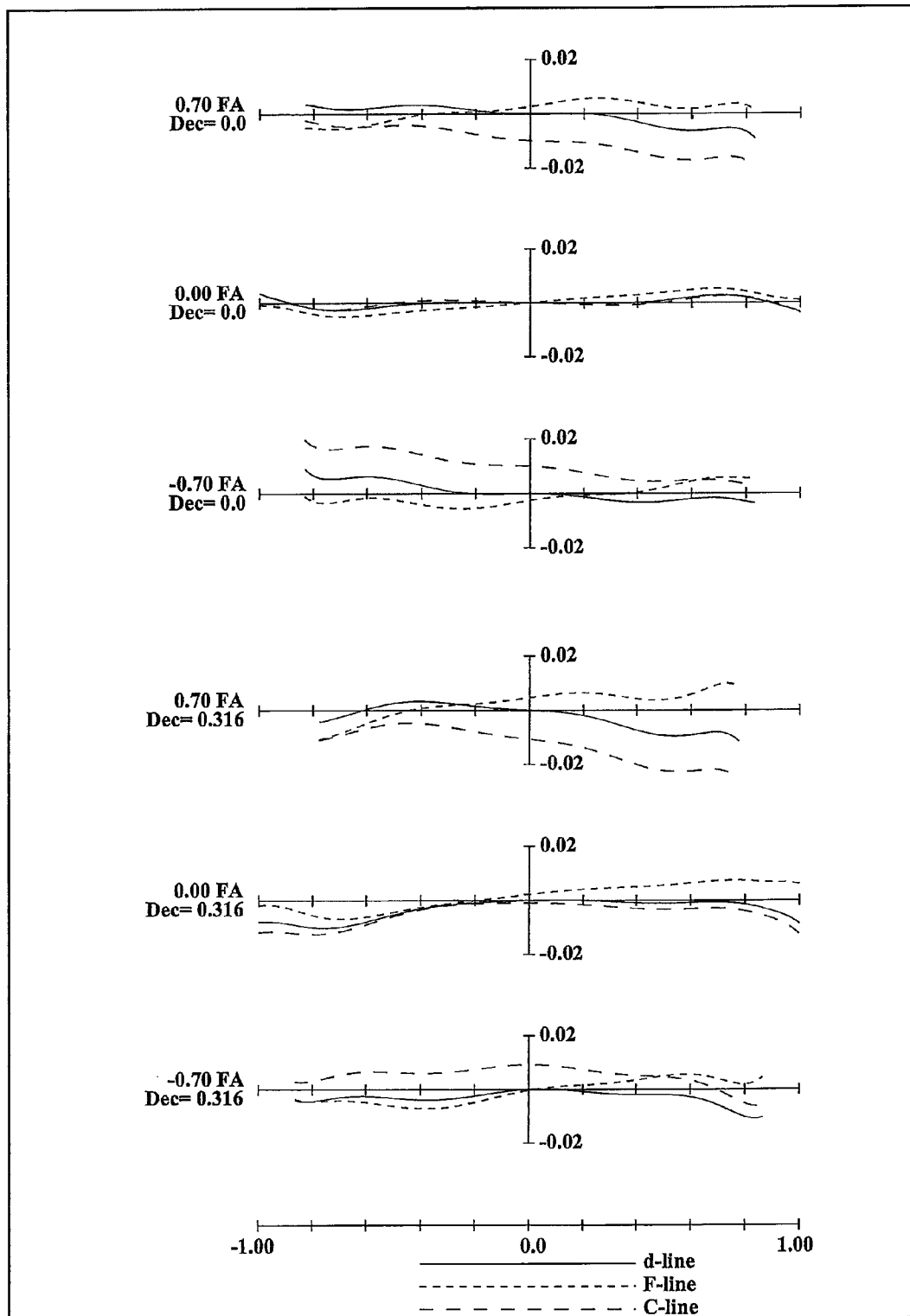


FIG. 7

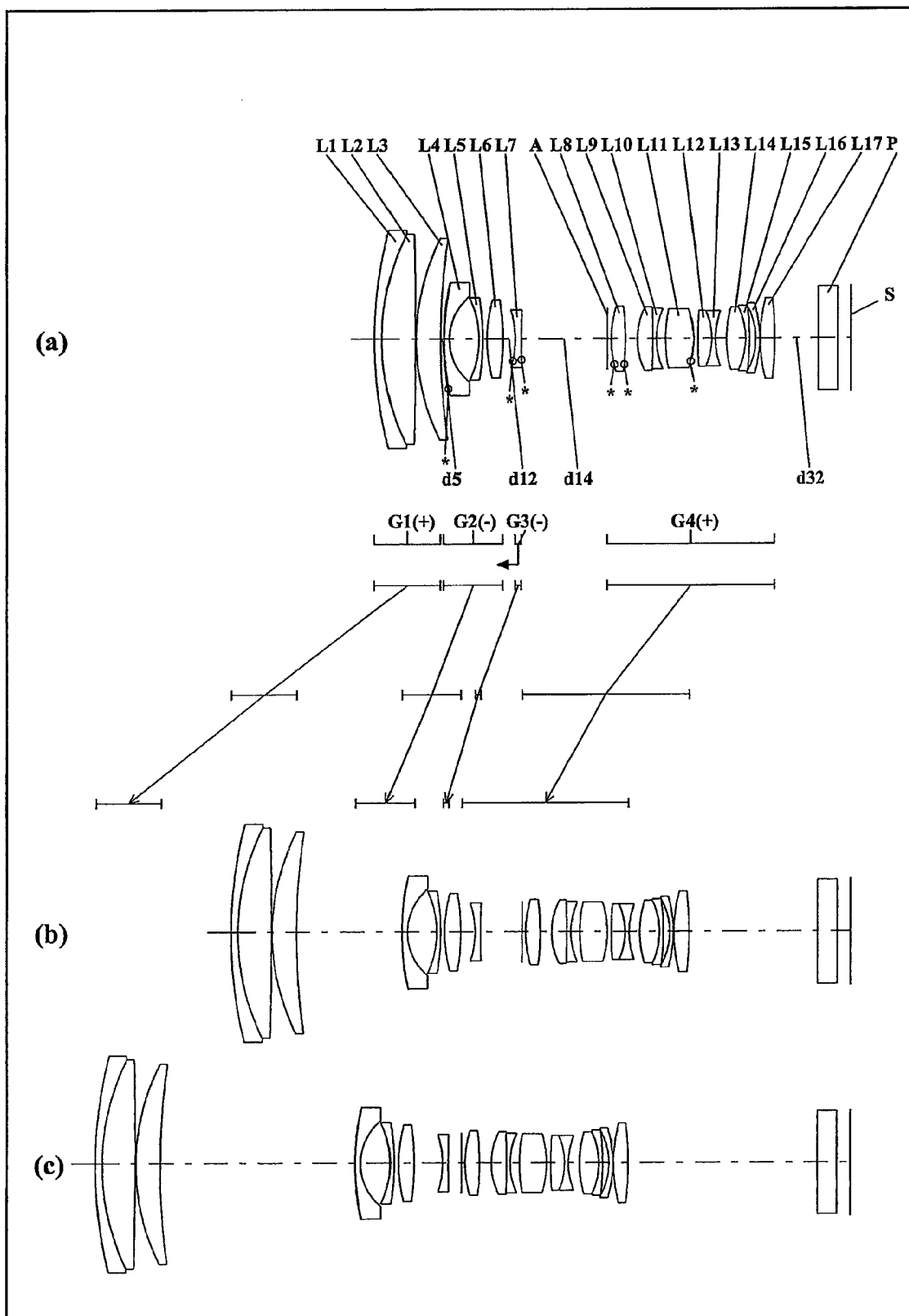


FIG. 8

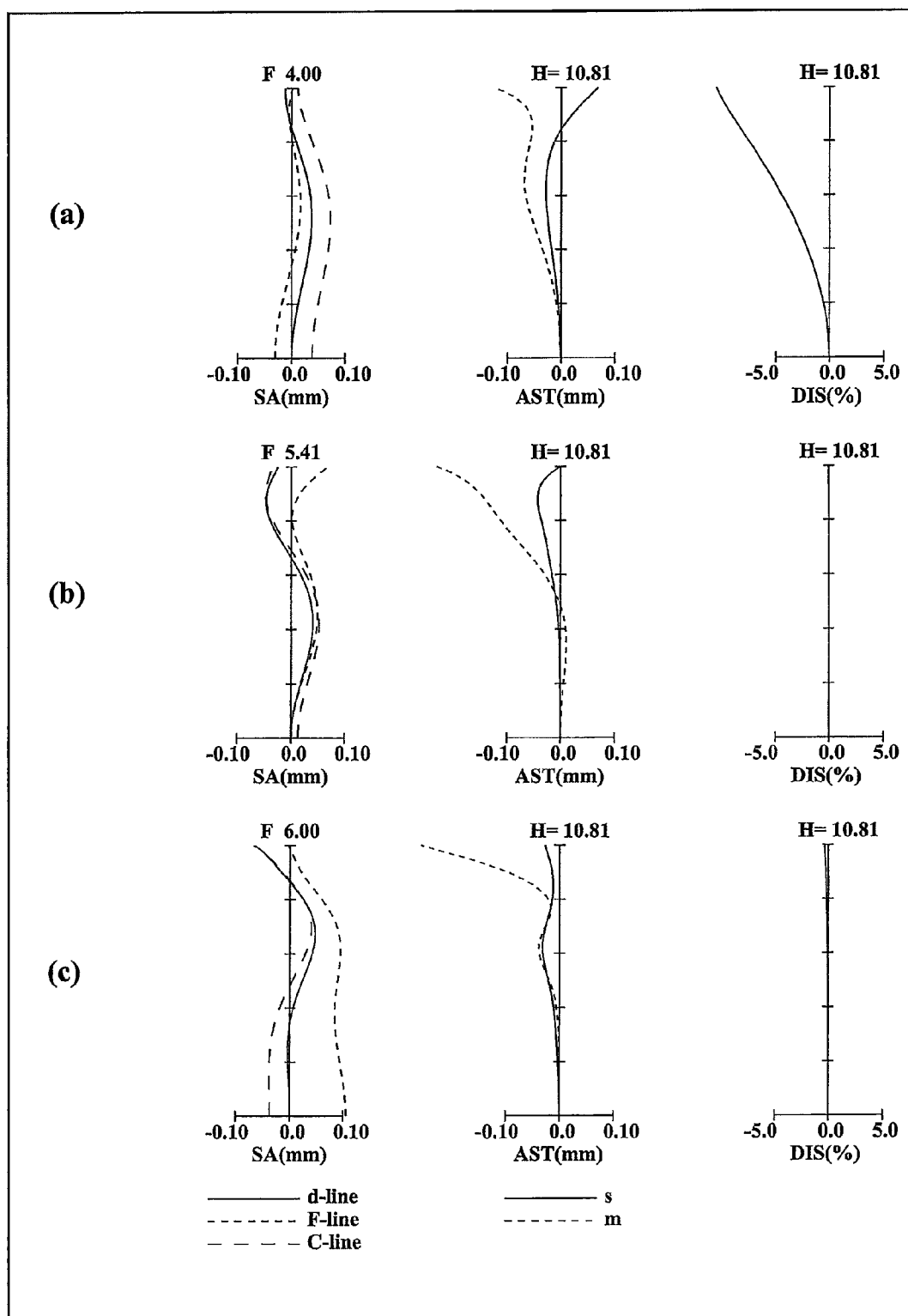


FIG. 9

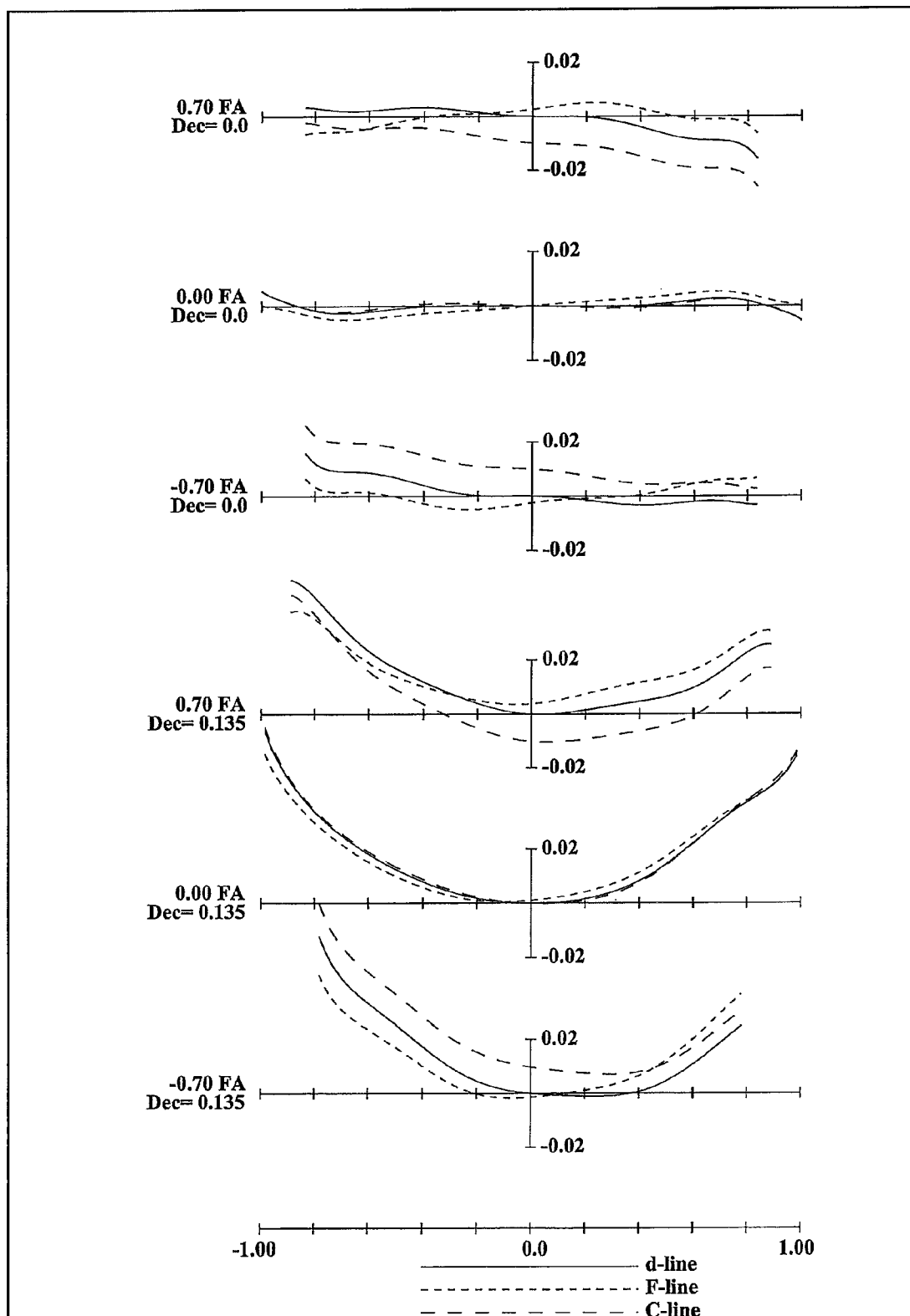


FIG. 10

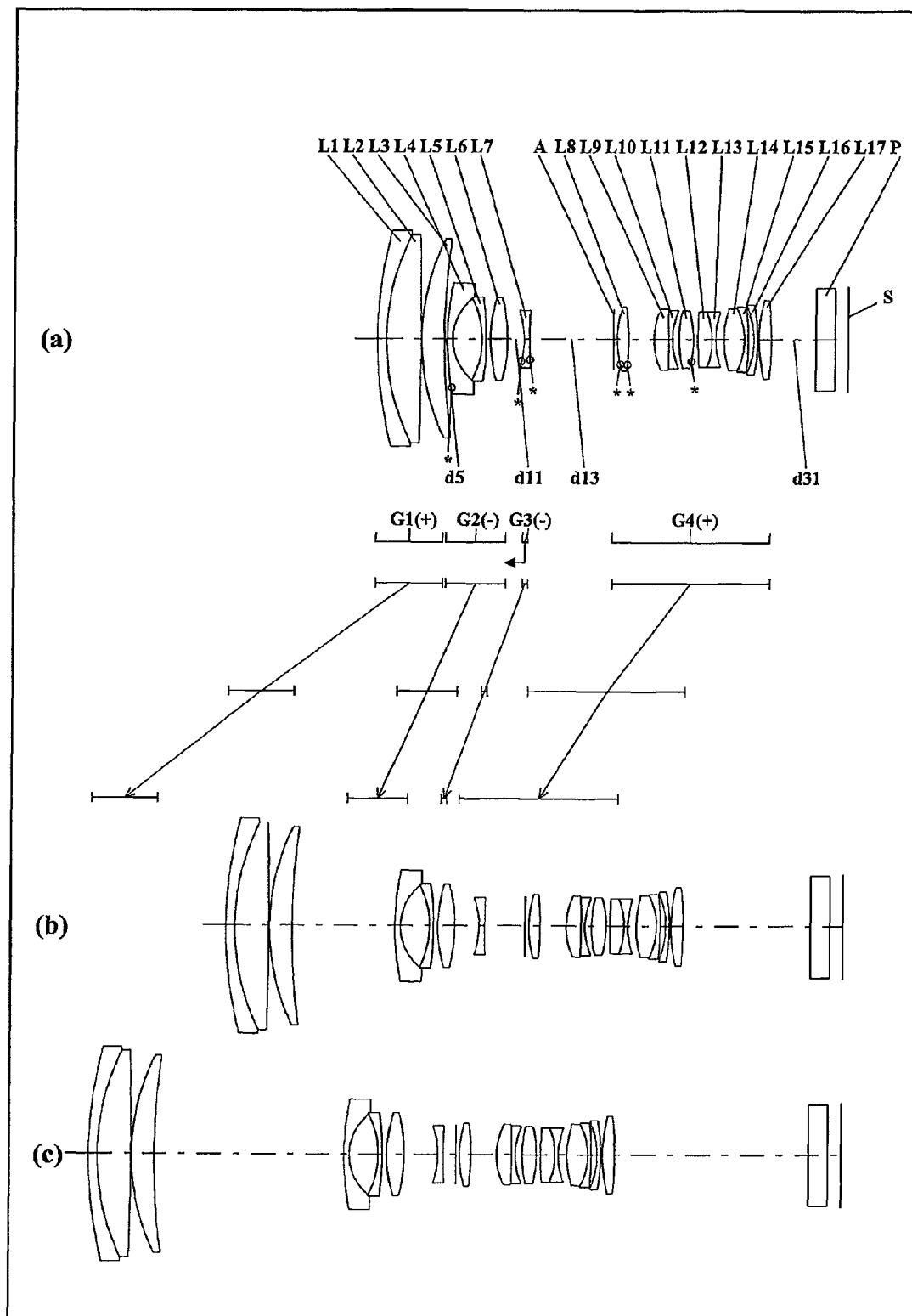


FIG. 11

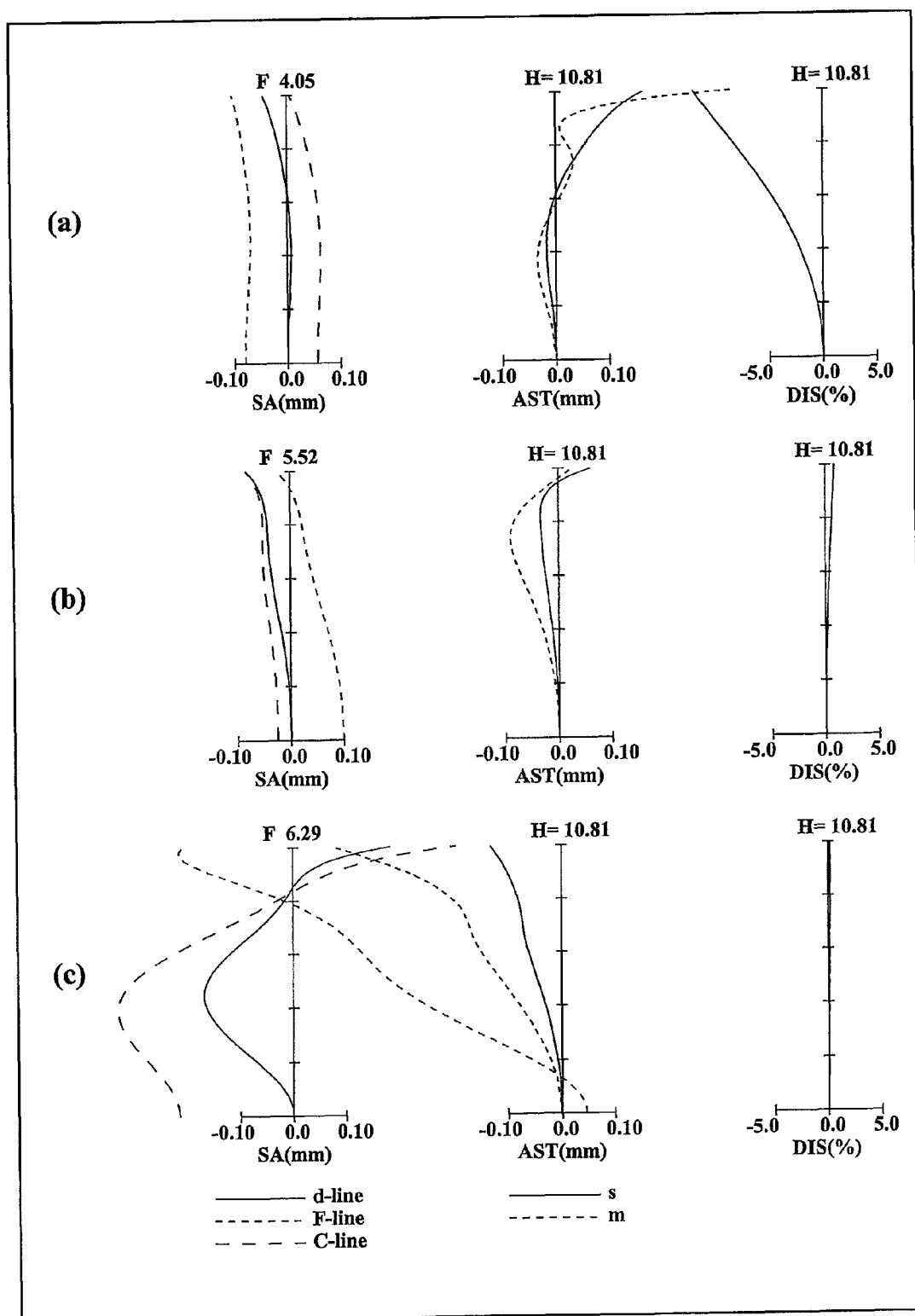


FIG. 12

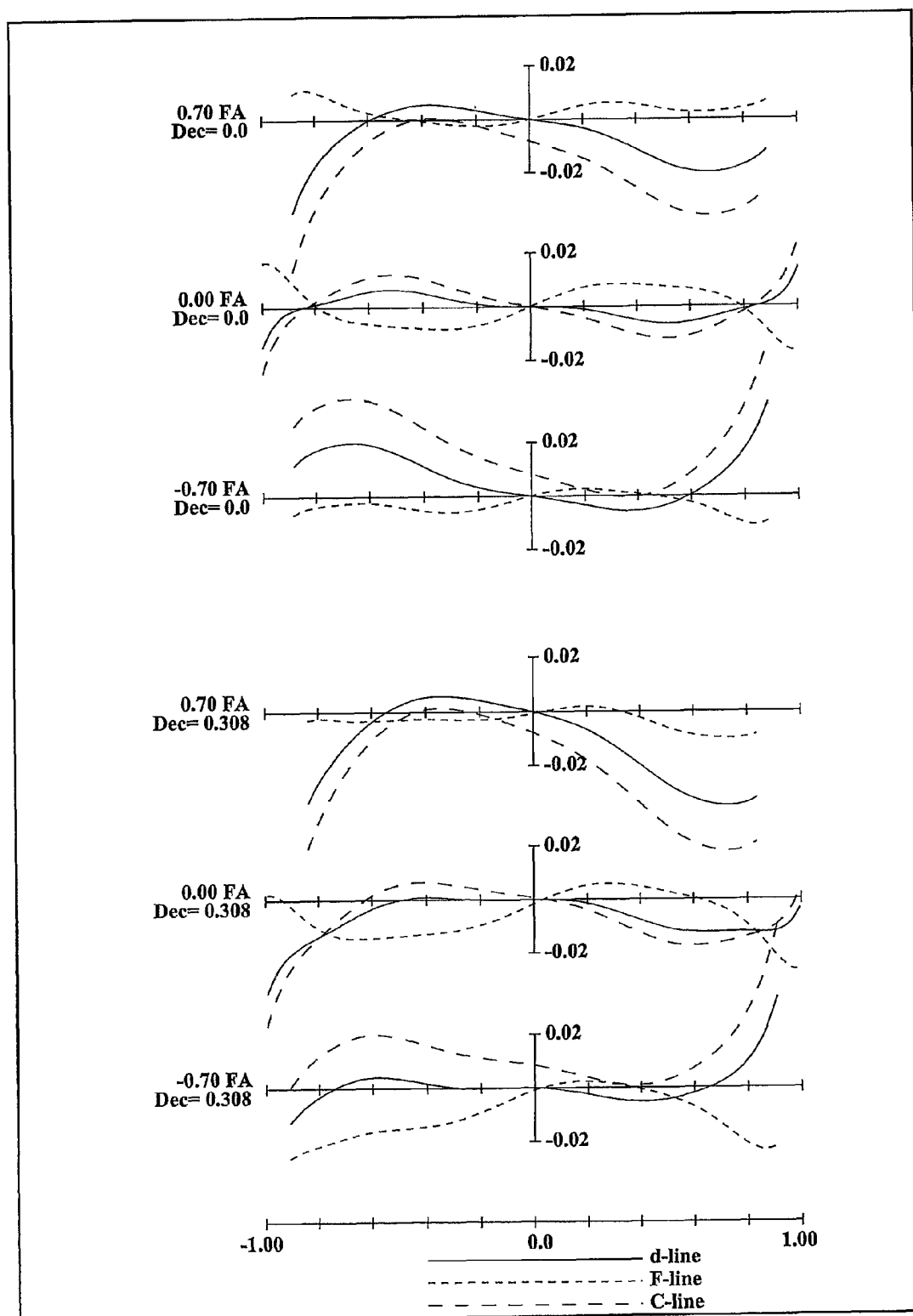


FIG. 13

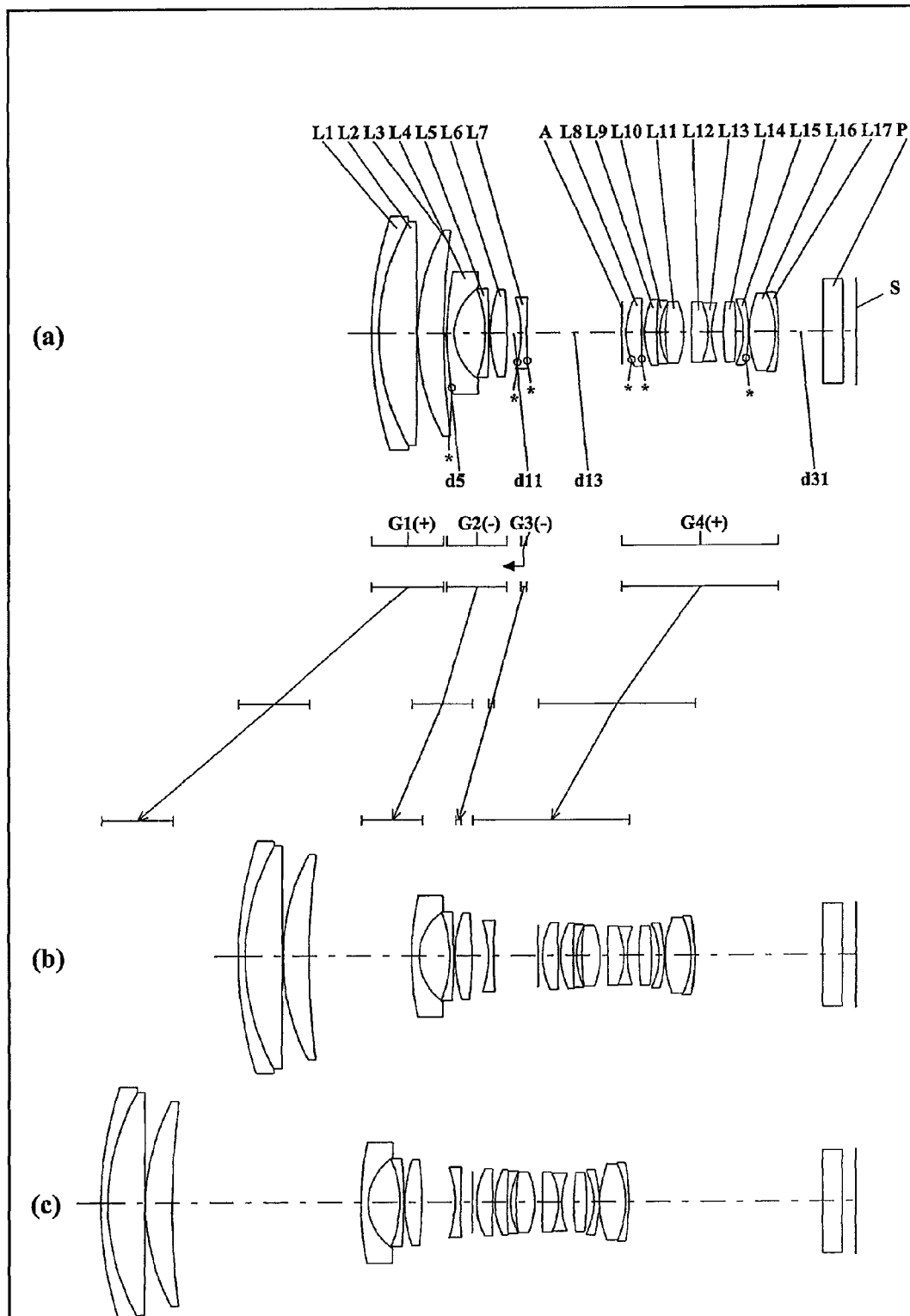


FIG. 14

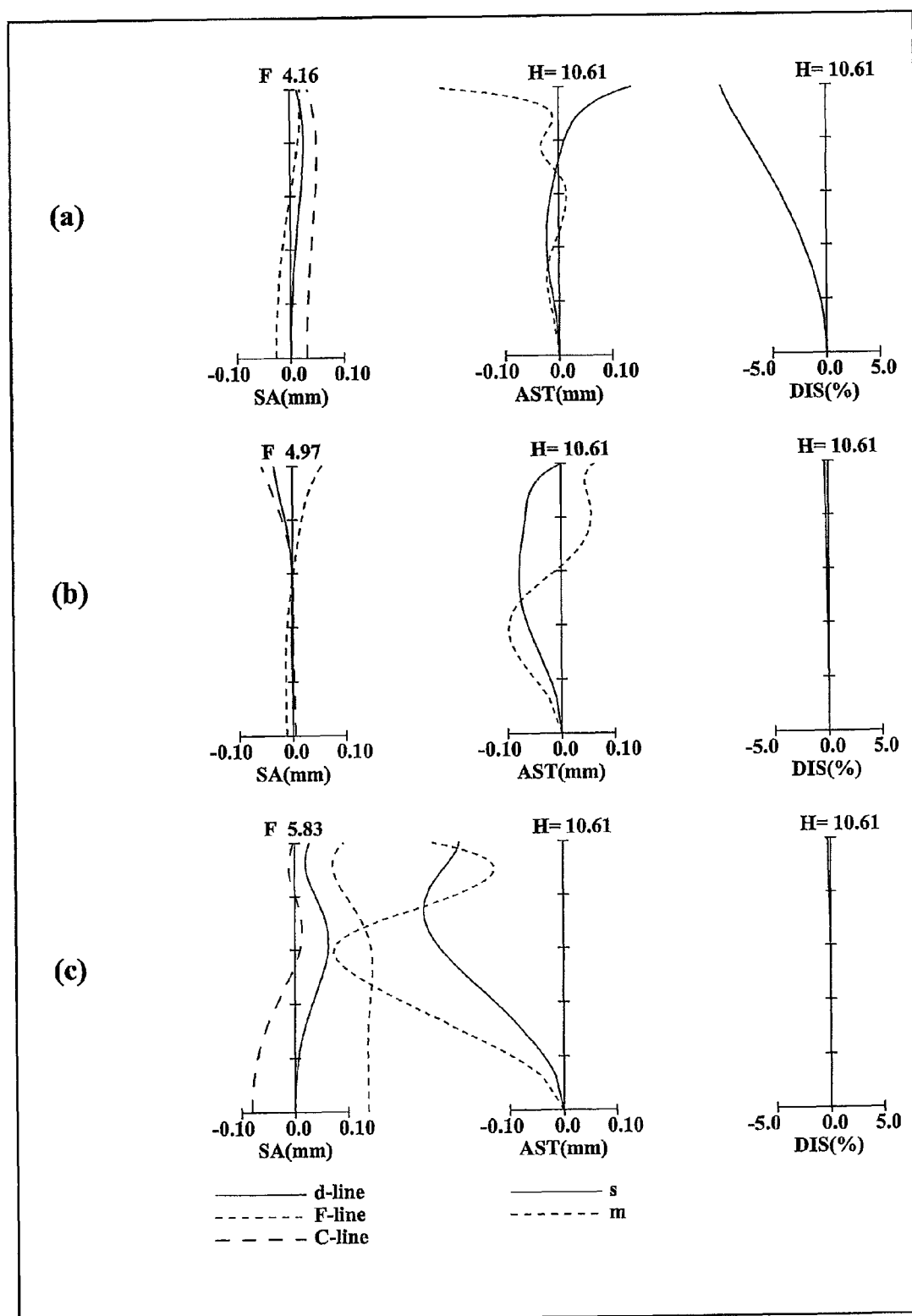


FIG. 15

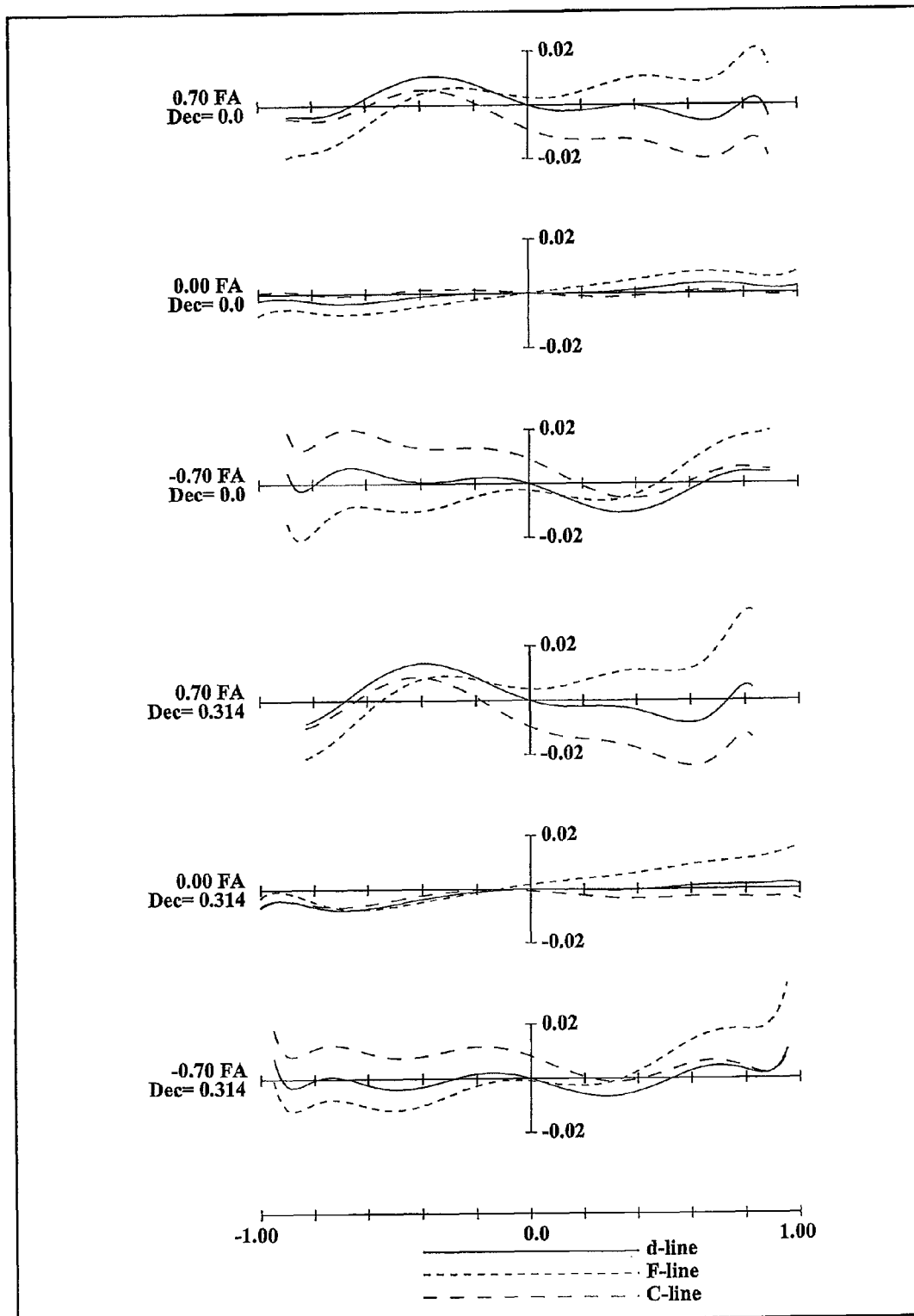
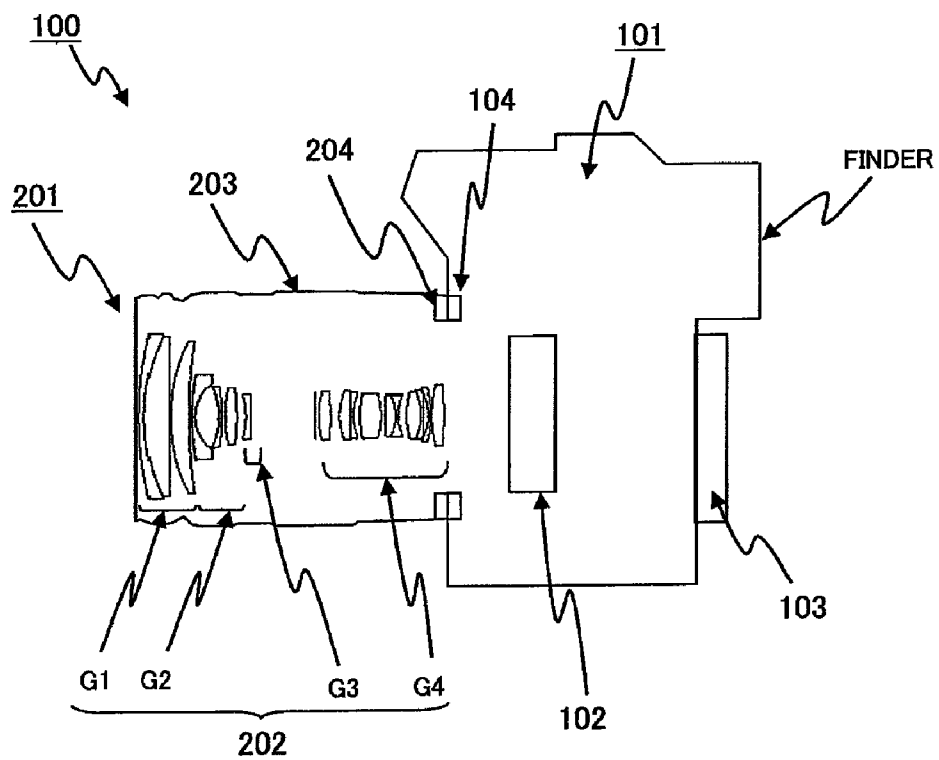


FIG. 16



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ZOOM LENS SYSTEM, INTERCHANGEABLE LENS APPARATUS AND CAMERA SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Application No. 2009-020091 filed on Jan. 30, 2009. Hereby, the contents of Japanese Patent Application No. 2009-020091 are incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a zoom lens system and, in particular, to a zoom lens system suitable for an imaging lens system employed in an interchangeable lens apparatus in a so-called interchangeable-lens type digital camera system. Further, the present invention relates to an interchangeable lens apparatus and a camera system that employ this zoom lens system.

2. Description of the Background Art

In recent years, interchangeable-lens type digital cameras are rapidly spreading. The interchangeable-lens type digital camera is a camera system including: a camera body employing an image sensor composed of a CCD (Charge Coupled Device), a CMOS (Complementary Metal-Oxide Semiconductor), or the like; and an interchangeable lens apparatus employing an imaging lens system for forming an optical image on the light acceptance surface of the image sensor. Zoom lens systems applicable to the above interchangeable-lens type digital camera are disclosed in Japanese Laid-Open Patent Publication No. 2005-284097, Japanese Laid-Open Patent Publication No. 2005-352057, Japanese Laid-Open Patent Publication No. 2006-221092, Japanese Laid-Open Patent Publication No. 2005-316396, Japanese Laid-Open Patent Publication No. 2006-267425, Japanese Laid-Open Patent Publication No. 2007-219315, Japanese Laid-Open Patent Publication No. 2008-3195, and Japanese Laid-Open Patent Publication No. 2008-15251.

On the other hand, there are interchangeable-lens type digital cameras employing a function of displaying image data generated by the imaging lens system or the image sensor on a display unit such as a liquid crystal display or the like of a camera body (hereinafter referred to as "live view function") (e.g., Japanese Laid-Open Patent Publication No. 2000-111789 and Japanese Laid-Open Patent Publication No. 2000-333064).

In the interchangeable-lens type digital cameras disclosed in Japanese Laid-Open Patent Publication No. 2000-111789 and Japanese Laid-Open Patent Publication No. 2000-333064, when the live view function is being performed, a contrast AF method is employed to perform focusing operation. The contrast AF is the focusing operation based on the contrast value of image data obtained from the image sensor. Hereinafter, an operation of the contrast AF will be described.

First, the interchangeable-lens type digital camera oscillates the focusing lens unit in the optical axis direction at a high-speed (hereinafter referred to as "wobbling") thereby to detect the direction of displacement from an in-focus condition. After the wobbling, the interchangeable-lens type digital camera detects, from an output signal of the image sensor, signal components in a predetermined frequency band in an image region and calculates an optimal position of the focusing lens unit for realizing the in-focus condition. Thereafter, the interchangeable-lens type digital camera moves the focusing lens unit to the optimal position, and completes the

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focusing operation. When the focusing operation is performed continuously in video image taking or the like, the interchangeable-lens type digital camera repeats a series of the above operations.

Generally, in order that uneasiness such as flickers should be avoided, video displaying need be performed at a high rate of, for example, 30 frames per second. Thus, basically, video image taking using the interchangeable-lens type digital camera also need be performed at the same rate of 30 frames per second. Accordingly, the focusing lens unit need be driven at the high rate of 30 Hz at the time of wobbling.

However, if the weight of the focusing lens unit is large, a larger motor or actuator is required to move the focusing lens unit at a high rate. This causes a problem that the outer diameter of the lens barrel is increased. However, in the case of the zoom lens systems for the interchangeable-lens type digital camera disclosed in the above conventional arts, the focusing lens unit is hardly light-weighted.

Further, in the interchangeable-lens type digital camera, it should be noted that the size of the image corresponding to a photographic object varies in association with wobbling. This variation in the image is caused mainly by the fact that the movement of the focusing lens unit in the optical axis direction generates a change in the focal length of the entire lens system. Then, when a large change in the image taking magnification is generated in association with wobbling, the image taking person will feel uneasiness.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a zoom lens system which includes a compactly constructed focusing lens unit and which has a suppressed change in the image magnification at the time of movement of the focusing lens unit, and an interchangeable lens apparatus and a camera system which employ this zoom lens system.

A zoom lens system according to the present invention, in order from an object side to an image side, includes: a first lens unit having positive optical power; a second lens unit having negative optical power; a third lens unit having negative optical power; and a fourth lens unit having positive optical power. At the time of zooming, at least the first lens unit moves from a wide-angle limit to a telephoto limit. The fourth lens unit includes a first sub lens unit having positive optical power and a second sub lens unit having negative optical power, the second sub lens unit being arranged at the image side relative to the first sub lens unit. At the time of compensating image blur caused by vibration applied to the zoom lens system, the first sub lens unit or the second sub lens unit moves in a direction perpendicular to the optical axis.

Further, an interchangeable lens apparatus according to the present invention includes: any of the above zoom lens systems; and a mount section detachably connected to a camera body that includes an image sensor which receives an optical image formed by the zoom lens system thereby to convert the optical image to an electrical image signal.

Moreover, a camera system according to the present invention includes: an interchangeable lens apparatus including any of the above zoom lens systems; and a camera body which is connected to the interchangeable lens apparatus via a camera mount section in an attachable and removable manner and includes an image sensor which receives an optical image formed by the zoom lens system thereby to convert the optical image to an electrical image signal.

According to the present invention, it is possible to provide a zoom lens system which includes a compactly constructed focusing lens unit and which has a suppressed change in

image magnification at the time of movement of the focusing lens unit, and an interchangeable lens apparatus and a camera system which employ the zoom lens system.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a lens arrangement diagram showing an infinity in-focus condition of a zoom lens system according to Embodiment 1 (Example 1);

FIG. 2 is a longitudinal aberration diagram showing an infinity in-focus condition of a zoom lens system according to Example 1;

FIG. 3 is a lateral aberration diagram in a basic state where image blur compensation is not performed and in an image blur compensation state at a telephoto limit of a zoom lens system according to Example 1;

FIG. 4 is a lens arrangement diagram showing an infinity in-focus condition of a zoom lens system according to Embodiment 2 (Example 2);

FIG. 5 is a longitudinal aberration diagram showing an infinity in-focus condition of a zoom lens system according to Example 2;

FIG. 6 is a lateral aberration diagram in a basic state where image blur compensation is not performed and in an image blur compensation state at a telephoto limit of a zoom lens system according to Example 2;

FIG. 7 is a lens arrangement diagram showing an infinity in-focus condition of a zoom lens system according to Embodiment 3 (Example 3);

FIG. 8 is a longitudinal aberration diagram showing an infinity in-focus condition of a zoom lens system according to Example 3;

FIG. 9 is a lateral aberration diagram in a basic state where image blur compensation is not performed and in an image blur compensation state at a telephoto limit of a zoom lens system according to Example 3;

FIG. 10 is a lens arrangement diagram showing an infinity in-focus condition of a zoom lens system according to Embodiment 4 (Example 4);

FIG. 11 is a longitudinal aberration diagram showing an infinity in-focus condition of a zoom lens system according to Example 4;

FIG. 12 is a lateral aberration diagram in a basic state where image blur compensation is not performed and in an image blur compensation state at a telephoto limit of a zoom lens system according to Example 4;

FIG. 13 is a lens arrangement diagram showing an infinity in-focus condition of a zoom lens system according to Embodiment 5 (Example 5);

FIG. 14 is a longitudinal aberration diagram showing an infinity in-focus condition of a zoom lens system according to Example 5;

FIG. 15 is a lateral aberration diagram in a basic state where image blur compensation is not performed and in an image blur compensation state at a telephoto limit of a zoom lens system according to Example 5; and

FIG. 16 is a schematic construction diagram of a camera system according to Embodiment 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1, 4, 7, 10, and 13 show lens arrangement diagrams of zoom lens systems according to Embodiments 1, 2, 3, 4, and 5, respectively, and each show a zoom lens system in a infinity in-focus condition.

In each diagram, part (a) shows a lens configuration at a wide-angle limit (in the minimum focal length condition: focal length f_w), part (b) shows a lens configuration at a middle position (in an intermediate focal length condition: focal length $f_M = \sqrt{(f_w * f_T)}$), and part (c) shows a lens configuration at a telephoto limit (in the maximum focal length condition: focal length f_T). Further, in each diagram, each bend arrow located between part (a) and part (b) indicates a line obtained by connecting the positions of the lens units respectively at a wide-angle limit, a middle position, and a telephoto limit, in order from the top. In the part between the wide-angle limit and the middle position, and the part between the middle position and the telephoto limit, the positions are connected simply with a straight line, and hence this line does not indicate actual motion of each lens unit. Moreover, in each diagram, an arrow imparted to a lens unit indicates focusing from an infinity in-focus condition to a close-object in-focus condition. That is, the arrow indicates the moving direction at the time of focusing from an infinity in-focus condition to a close-object in-focus condition.

In FIGS. 1, 4, 7, 10, and 13, an asterisk "*" imparted to a particular surface indicates that the surface is aspheric. Further, in each diagram, symbol (+) or symbol (-) imparted to the symbol of each lens unit corresponds to the sign of the optical power of the lens unit. Still further, in each diagram, the straight line located on the most right-hand side indicates the position of the image surface S. On the object side relative to the image surface S (between the image surface S and a surface of a lens closest to the image side in the fourth lens unit G4), there is arranged a parallel plate P which corresponds to an optical low-pass filter, a face plate of an image sensor, or the like. Further, in each diagram, an aperture diaphragm A is arranged on the object side relative to the fourth lens unit G4 while an interval which does not change at the time of zooming is arranged therebetween.

The zoom lens system according to each of Embodiments 1 to 5, in order from the object side to the image side, includes a first lens unit G1 having positive optical power, a second lens unit G2 having negative optical power, a third lens unit G3 having negative optical power, and a fourth lens unit G4 having positive optical power.

Embodiments 1 to 3

The first lens unit G1, in order from the object side to the image side, includes: a negative meniscus first lens element L1 with the convex surface facing the object side; a bi-convex second lens element L2; and a positive meniscus third lens element L3 with the convex surface facing the object side. The first lens element L1 and the second lens element L2 are cemented with each other.

The second lens unit G2, in order from the object side to the image side, includes: a negative meniscus fourth lens element L4 with the convex surface facing the object side; a negative meniscus fifth lens element L5 with the convex surface facing the image side; and a bi-convex sixth lens element L6. The fourth lens element L4 is a hybrid lens obtained by cementing a transparent resin layer formed of a UV cured resin onto a surface of the lens element facing the object side. The hybrid lens has an aspheric surface formed of a transparent resin layer. Accordingly, it is possible to form a large diameter aspheric surface which is difficult to obtain by only press-molding of glass. Further, as compared to the case where the lens element is formed of a resin only, the hybrid lens is stable against temperature variation in terms of both refractive-index variation and shape variation, and thus it is possible to provide a lens element having a high refractive index.

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The third lens unit G3 includes: a bi-concave seventh lens element L7. Both surfaces of the seventh lens element L7 are aspheric.

The fourth lens unit G4, in order from the object side to the image side; includes: a bi-convex eighth lens element L8; a bi-convex ninth lens element L9; a bi-concave tenth lens element L10; a bi-convex eleventh lens element L11, a bi-convex twelfth lens element L12; a bi-concave thirteenth lens element L13; a bi-convex fourteenth lens element L14; a negative meniscus fifteenth lens element L15 with the convex surface facing the image side; a negative meniscus sixteenth lens element L16 with the convex surface facing the image side; and a bi-convex seventeenth lens element L17. The ninth lens element L9 and the tenth lens element L10 are cemented with each other. The twelfth lens element L12 and the thirteenth lens element L13 are cemented with each other. Moreover, the fourteenth lens element L14 and the fifteenth lens element L15 are cemented with each other. Further, both surfaces of the eighth lens element L8 and a surface of the eleventh lens element L11 facing the image side are aspheric.

Embodiment 4

The first lens unit G1, in order from the object side to the image side, includes: a negative meniscus first lens element L1 with the convex surface facing the object side; a bi-convex second lens element L2; and a positive meniscus third lens element L3 with the convex surface facing the object side. The first lens element L1 and the second lens element L2 are cemented with each other.

The second lens unit G2, in order from the object side to the image side, includes: a negative meniscus fourth lens element L4 with the convex surface facing the object side; a negative meniscus fifth lens element L5 with the convex surface facing the image side; and a bi-convex sixth lens element L6. A surface of the fourth lens element L4 facing the object side is aspheric.

The third lens unit G3 includes: a bi-concave seventh lens element L7. Both surfaces of the seventh lens element L7 are aspheric.

The fourth lens unit G4, in order from the object side to the image side; includes: a bi-convex eighth lens element L8; a bi-convex ninth lens element L9; a bi-concave tenth lens element L10; a bi-convex eleventh lens element L11, a bi-convex twelfth lens element L12; a bi-concave thirteenth lens element L13; a bi-convex fourteenth lens element L14; a negative meniscus fifteenth lens element L15 with the convex surface facing the image side; a negative meniscus sixteenth lens element L16 with the convex surface facing the image side; and a bi-convex seventeenth lens element L17. The ninth lens element L9 and the tenth lens element L10 are cemented with each other. The twelfth lens element L12 and the thirteenth lens element L13 are cemented with each other. Moreover, the fourteenth lens element L14 and the fifteenth lens element L15 are cemented with each other. Further, both surfaces of the eighth lens element L8 and a surface of the eleventh lens element L11 facing the image side are aspheric.

Embodiment 5

The first lens unit G1, in order from the object side to the image side, includes: a negative meniscus first lens element L1 with the convex surface facing the object side; a bi-convex second lens element L2; and a positive meniscus third lens element L3 with the convex surface facing the object side. The first lens element L1 and the second lens element L2 are cemented with each other.

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The second lens unit G2, in order from the object side to the image side, includes: a negative meniscus fourth lens element L4 with the convex surface facing the object side; a negative meniscus fifth lens element L5 with the convex surface facing the image side; and a bi-convex sixth lens element L6. A surface of the fourth lens element L4 facing the object side is aspheric.

The third lens unit G3 includes: a bi-concave seventh lens element L7. Both surfaces of the seventh lens element L7 are aspheric.

The fourth lens unit G4, in order from the object side to the image side; includes: a bi-convex eighth lens element L8; a positive meniscus ninth lens element L9 with the convex surface facing the object side; a negative meniscus tenth lens element L10 with the convex surface facing the object side; a bi-convex eleventh lens element L11, a bi-convex twelfth lens element L12; a bi-concave thirteenth lens element L13; a bi-convex fourteenth lens element L14; a negative meniscus fifteenth lens element L15 with the convex surface facing the image side; a bi-convex sixteenth lens element L16; and a negative meniscus seventeenth lens element L17 with the convex surface facing the image side. The ninth lens element L9 and the tenth lens element L10 are cemented with each other. The twelfth lens element L12 and the thirteenth lens element L13 are cemented with each other. Moreover, the sixteenth lens element L16 and the seventeenth lens element L17 are cemented with each other. Further, both surfaces of the eighth lens element L8 and a surface of the fifteenth lens element L15 facing the image side are aspheric.

The zoom lens system according to each of the embodiments changes intervals among respective lens units at the time of zooming such that: the interval between the first lens unit G1 and the second lens unit G2 is made longer at a telephoto limit than the interval at a wide-angle limit; the interval between the second lens unit G2 and the third lens unit G3 is made longer at a telephoto limit than the interval at a wide-angle limit; and the interval between the third lens unit G3 and the fourth lens unit G4 is made shorter at a telephoto limit than the interval at a wide-angle limit.

More specifically, at the time of zooming from a wide-angle limit to a telephoto limit, the individual lens units move in a direction along the optical axis monotonously to the object side such that: the interval between the first lens unit G1 and the second lens unit G2, and the interval between the second lens unit G2 and the third lens unit G3 are increased, respectively; whereas the interval between the third lens unit G3 and the fourth lens unit G4 is decreased. It is noted that in any of the embodiments, the aperture diaphragm A moves to the object side together with the fourth lens unit G4.

Further, at the time of focusing from an infinity in-focus condition to a close-point in-focus condition, the third lens unit G3 moves to the object side along the optical axis.

To allow video taking, the focusing lens unit need have high-speed response while wobbling operation. In the zoom lens system according to each of the above Embodiments 1 to 5, the third lens unit G3 is composed of one lens element, whereby a focusing lens unit having a reduced weight and high-speed response is realized. It is noted that the focusing lens unit need not necessarily be formed of one lens element. If the torque performance of the actuator allows, the focusing lens unit may include two lens elements. Further, in order to minimize fluctuation in performance in focusing from infinity to a close-point distance, the focusing lens unit has an aspheric surface. The aspheric surface may be a hybrid aspheric surface.

In the zoom lens system according to Embodiments 1 to 5, the fourth lens unit G4 is arranged closest to the object side,

when the fourth lens unit, in order from the image side to the object side, includes; a lens element having positive optical power; a lens element having negative optical power; a lens element having negative optical power; and a lens ele-

ment having positive optical power, f_{4Im} , is a composite focal length of the four lens elements; and

$f_{4\alpha}$ is a composite focal length of the fourth lens unit and a lens unit subsequent thereto at a wide-angle limit.

The condition (4) sets forth the ratio between the composite focal length of four lens elements arranged closest to the object side in the fourth lens unit and the composite focal length of the fourth lens unit and a lens unit subsequent thereto. When the value exceeds the upper limit of the condition (4), the distortion at a wide-angle limit becomes excessive toward the over side. Thus, this situation is unpreferable. Further, the value goes below the lower limit of the condition (4), the back focus is elongated, and the overall length cannot be compact.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$1.0 < f_{4\alpha}/f_w < 1.5 \quad (5)$$

where,

$f_{4\alpha}$ is a composite focal length of the fourth lens unit and a lens unit subsequent thereto at a wide-angle limit, and

f_w is a focal length of the entire system at a wide-angle limit.

The condition (5) sets forth the focal length of the fourth lens unit and a lens unit subsequent thereto. When the value exceeds the upper limit of the condition (5), the incident angle relative to the image surface is increased, and it becomes difficult to secure the telecentricity. Further, when the value goes below the lower limit of the condition (5), it is not desirable since the flange back cannot be obtained.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-1.6 < f_F/f_{4\alpha} < -0.7 \quad (6)$$

where,

f_F is a focal length of the focusing lens unit, and

$f_{4\alpha}$ is a composite focal length of the fourth lens unit and a lens unit subsequent thereto at a wide-angle limit.

The condition (6) sets forth the ratio between the focal length of the focusing lens unit and the composite focal length of the fourth lens unit and a lens unit subsequent thereto. When the value exceeds the upper limit of the condition (6), the fluctuation in the field curvature at the time of focusing increases. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (6), it may cause upsizing of the optical system when the amount of movement in association with focusing is large. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$12 < f_1^*(f_T/f_w)/\sqrt{(f_w^*f_T)} < 27 \quad (7)$$

where,

f_1 is a focal length of the first lens unit,

f_T is a focal length of the entire system at a telephoto limit, and

f_w is a focal length of the entire system at a wide-angle limit.

The condition (7) sets forth the relation between the focal length of the first lens unit and the focal length of the entire system. When the value exceeds the upper limit of the condition (7), it causes an increase in the amount of movement of the first unit from a wide-angle limit to a telephoto limit, and as a result, an intersection angle (pressure angle) of the cam become acute, resulting in fluctuation in load of the cam. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (7), it becomes

difficult to compensate the magnification chromatic aberration generated in the first lens unit by using the subsequent lens units. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-20 < f_2^*(f_T/f_w)/\sqrt{(f_w^*f_T)} < -6 \quad (8)$$

where,

f_2 is a focal length of the second lens unit,

f_T is a focal length of the entire system at a telephoto limit, and

f_w is a focal length of the entire system at a wide-angle limit.

The condition (8) sets forth the relation between the focal length of the second lens unit and the focal length of the entire system. When the value exceeds the upper limit of the condition (8), the negative optical power of the second lens unit is excessively increased, and the field curvature is apt to be toward the under side, and as a result, the difference in the peripheral image surface increases between the wide-angle limit and the telephoto limit at the time of variation of magnification. Thus, the situation is not preferable. Further, when the value goes below the lower limit of the condition (8), the negative optical power of the second lens unit is excessively decreased, and the field curvature is apt to be toward the over side, and as a result, the difference in the peripheral image surface increases between the wide-angle limit and the telephoto limit at the time of variation of magnification. Thus, this situation is not preferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$0.5 < \delta t_1/f_1 < 1.1 \quad (9)$$

where,

δt_1 is an amount of movement of the first lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as the reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_1 is a focal length of the first lens unit.

The condition (9) sets forth the amount of movement of the first lens unit in the optical axis direction. When the value exceeds the upper limit of the condition (9), with a moving mechanism of the first lens unit being configured with a cam, it is difficult to smoothly form the curve of the cam groove. When the value of the condition (9) goes below the lower limit, the overall length is elongated at a wide-angle limit, or the overall length is shortened at a telephoto limit. When the overall length is elongated at a wide-angle limit, a front lens diameter increases. Thus, this is unpreferable. On the other hand, when the overall length is shortened at a telephoto limit, the sensitivity of the first lens unit increases. This situation is unpreferable from the viewpoint of manufacturing.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-0.7 < \delta t_2/f_2 < -0.2 \quad (10)$$

where,

δt_2 is an amount of movement of the second lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as the reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_2 is a focal length of the second lens unit.

The condition (10) sets forth the amount of movement of the second lens unit in the optical axis direction. When the value exceeds the upper limit of the condition (10), the posi-

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tion of the incident pupil moves considerably deeply to the image surface side, which causes increase in the front lens diameter. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (10), the power of the second lens unit increases, and this causes difficulty in compensating aberration. If the aberration compensation is to be performed, the number of lenses will be increased. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-1.2 < \delta t_3 / f_3 < -0.4 \quad (11)$$

where,

δt_3 is an amount of movement of the third lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as the reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_3 is a focal length of the third lens unit.

The condition (11) sets forth the amount of movement of the third lens unit in the optical axis direction. When the value exceeds the upper limit of the condition (11), up-sizing of the actuator for focusing will be caused. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (11), the power of the third lens unit increases, and sensitivity for decentering increases. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$1.2 < \delta t_4 / f_4 < 2.0 \quad (12)$$

where,

δt_4 is an amount of movement of the fourth lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as the reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_4 is a focal length of the fourth lens unit.

The condition (12) sets forth the amount of movement of the fourth lens unit in the optical axis direction. When the value exceeds the upper limit of the condition (12), the overall length of the entire system is elongated at a telephoto limit, and thus the amount of movement of the first lens unit from a wide-angle limit to a telephoto limit increases. When a moving mechanism of the first lens unit is configured with a cam, the intersection angle (pressure angle) of the cam becomes acute, resulting in fluctuation in load of the cam. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (12), the power of the second lens unit increases, and fluctuation in the field curvature increases from a wide-angle limit to a telephoto limit, which cause difficulty in its compensation. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-25 < \beta_{2T} / \beta_{2W} < 34 \quad (13)$$

where,

β_{2T} is paraxial imaging magnification of the second lens unit at a telephoto limit, and

β_{2W} is paraxial imaging magnification of the second lens unit at a wide-angle limit.

The condition (13) sets forth the change in magnification of the second lens unit. When the value exceeds the upper limit of the condition (13), it becomes difficult to compensate aberration from a wide-angle limit to a telephoto limit. Thus, this situation is unpreferable. Further, when the value goes

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below the lower limit of the condition (13), the amount of movement of the second lens unit from a wide-angle limit to a telephoto limit increases, and consequently, the overall length of the entire system is elongated. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-8 < \beta_{3T} / \beta_{3W} < 0.2 \quad (14)$$

where,

β_{3T} is paraxial imaging magnification of the third lens unit at a telephoto limit, and

β_{3W} is paraxial imaging magnification of the third lens unit at a wide-angle limit.

The condition (14) sets forth the change in magnification of the third lens unit. When the value exceeds the upper limit of the condition (14), the power of the third lens unit is increased, and fluctuation of an image at the time of focusing increases. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (14), the power of the third lens unit is decreased, the amount of movement of the third lens unit at the time of focusing increases. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$2 < \beta_{4T} / \beta_{4W} < 3.2 \quad (15)$$

where,

β_{4T} is paraxial imaging magnification of the fourth lens unit at a telephoto limit, and

β_{4W} is paraxial imaging magnification of the fourth lens unit at a wide-angle limit.

The condition (15) sets forth the change in magnification of the fourth lens unit. When the value exceeds the upper limit of the condition (15), the incident angle of light to be incident on the image surface at a wide-angle limit increases, and it becomes difficult to maintain the telecentricity. Thus, this situation is unpreferable. Further, when the value goes below the lower limit of the condition (15), the back focus is elongated at a wide-angle limit, and the entire system cannot be compact. Thus, this situation is unpreferable.

If the focusing lens unit included in the zoom lens system according to each embodiment has an aspheric surface, it is preferable that the following condition is satisfied.

$$-0.3 < f_F * \beta_{FW} * \beta_{FW}' / (\delta s_F * f_T / f_W) < 7.0 \quad (16)$$

where,

f_F is a focal length of the focusing lens unit,

β_{FW} is paraxial imaging magnification of the focusing lens unit at a wide-angle limit,

δs_F is an amount of deformation of an aspheric surface at a height of $0.5 * f_W * \tan \omega_W$ from the optical axis, the aspheric surface being arranged closest to the object side in the focusing lens unit,

f_T is a focal length of the entire system at a telephoto limit, f_W is a focal length of the entire system at a wide-angle limit, and

ω_W is a half view angle at a wide-angle limit.

The condition (16) sets forth the relation between the paraxial imaging magnification and the amount of aspheric aberration of the focusing lens unit. When the value exceeds the upper limit of the condition (16), the astigmatism and spherical aberration from an infinity distance at a telephoto limit to a close-point distance are increased to the under side, and thus this situation is unpreferable from the viewpoint of the aberration compensation. When the value goes below the lower limit of the condition (16), the aberration sensitivity

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relative to process errors increases, and thus fluctuation in the field curvature caused by manufacturing variation increases. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$-1.7\text{mm} < \text{DIS}_W * f_T / f_W < -0.5\text{mm} \quad (17)$$

where,

DIS_W is an amount of distortion of the maximum image height at a wide-angle limit,

f_T is a focal length of the entire system at a telephoto limit, and

f_W is a focal length of the entire system at a wide-angle limit.

The condition (17) sets forth the relation between the amount of distortion and a variable magnification ratio. In the case where the camera system is provided with a distortion compensation system, when the value exceeds the upper limit of the condition (17), the advantage of shortening of the overall length by the above system cannot be utilized. Thus, this situation is unpreferable. In contrast, when the value goes below the lower limit of the condition (17), the image magnification rate is increased in the distortion compensation process, resulting in degradation in resolution. Thus, this situation is unpreferable.

In the zoom lens system according to each embodiment, it is preferable that the following condition is satisfied.

$$1.88 < \text{nd}_2 \quad (18)$$

where,

nd_2 is an average refractive index of a lens element (a portion excluding a resin layer in the case of a hybrid lens) included in the second lens unit.

When the value goes below the lower limit of the condition (18), the distortion mainly at a wide-angle limit increases due to decrease in the curvature of the lens, which causes difficulty in compensating the aberration. Thus, this situation is unpreferable.

Here, the individual lens units included in the zoom lens system according to each embodiment may be composed exclusively of refractive type lens elements that deflect incident light by refraction (that is, lens elements of a type in which deflection is achieved at the interface between media each having a distinct refractive index). Alternatively, the lens may be composed of any one of, or a combination of some of: diffractive type lens elements that deflect the incident light by diffraction; refractive-diffractive hybrid type lens elements that deflect the incident light by a combination of diffraction and refraction; refractive index distribution type lens elements that deflect the incident light by distribution of refractive index in the medium, and the like.

Embodiment 6

FIG. 16 is a schematic construction diagram of a camera system according to Embodiment 6.

A camera system 100 according to the present embodiment includes a camera body 101, and an interchangeable lens apparatus 201 connected to the camera body 101 in an attachable and removable manner.

The camera body 101 includes an image sensor 102 which receives an optical image formed by a zoom lens system 202 of the interchangeable lens apparatus 201 thereby to convert the optical image into an electric image signal, a liquid crystal display monitor 103 which displays an image signal converted by the image sensor 102, and a camera mount section 104. On the other hand, the interchangeable lens apparatus

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201 includes the zoom lens system 202 according to any one of Embodiments 1 to 5, a lens barrel 203 which holds the zoom lens system 202, and a lens mount section 204 connected to the camera mount section 104 of the camera body.

The camera mount section 104 and the lens mount section 204 are connected to each other not only physically but also electrically, and function as interfaces. That is, a controller (not shown) inside the camera body 101 is electrically connected to a controller (not shown) inside the interchangeable lens apparatus 201, thereby achieving mutual signal communication.

The camera system 100 according to the present embodiment includes the zoom lens system 202 according to any one of Embodiments 1 to 5, and hence is capable of displaying an preferable optical image at the time of focusing in a live view state.

EXAMPLES

Hereinafter, numerical examples will be described below in which the zoom lens systems according to Embodiments 1 to 5 are implemented specifically. As will be described later, Numerical Examples 1 to 5 corresponds to Embodiments 1 to 5, respectively. Here, in each numerical example, the units of the length are all “mm”, while the units of the view angle are all “°”. Moreover, in the numerical examples, r is the radius of curvature, d is the axial distance, n_d is the refractive index to the d-line, and v_d is the Abbe number to the d-line. In the numerical examples, the surfaces marked with “*” are aspheric surfaces, and the aspheric surface configuration is defined by the following formula.

$$Z = \frac{h^2/r}{1 + \sqrt{1 - (1 + \kappa)(h/r)^2}} + \sum A_n h^n$$

Here, the symbols in the formula indicate the following quantities:

Z is the distance from an on-the-aspheric-surface point at a height h relative to the optical axis to a tangential plane at the top of the aspheric surface;

h is the height relative to the optical axis;

r is the radius of curvature at the top;

κ is the conic constant; and

A_n is the n -th order aspheric coefficient.

FIGS. 2, 5, 8, 11, and 14 are longitudinal aberration diagrams of an infinity in-focus condition of the zoom lens systems according to Numerical Examples 1, 2, 3, 4, and 5.

In each longitudinal aberration diagram, part (a) shows the aberration at a wide-angle limit, part (b) shows the aberration at a middle position, and part (c) shows the aberration at a telephoto limit. Each longitudinal aberration diagram, in order from the left-hand side, shows the spherical aberration (SA (mm)), the astigmatism (AST (mm)), and the distortion (DIS (%)). In each spherical aberration diagram, the vertical axis indicates the F-number (in each diagram, indicated as F), the solid line, the short dash line, and the long dash line indicate the characteristics to the d-line, the F-line, and the C-line, respectively. In each astigmatism diagram, the vertical axis indicates the image height (in each diagram, indicated as H), the solid line and the dash line indicate the characteristics to the sagittal image plane (in each diagram, indicated as “s”) and the meridional image plane (in each diagram, indicated as “m”), respectively. In each distortion diagram, the vertical axis indicates the image height (in each diagram, indicated as H).

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FIGS. 3, 6, 9, 12, and 15 are lateral aberration diagrams in a basic state where image blur compensation is not performed and in an image blur compensation state of a zoom lens system according to Numerical Examples 1, 2, 3, 4, and 5.

In each lateral aberration diagram, the aberration diagrams in the upper three parts correspond to a basic state where image blur compensation is not performed at a telephoto limit, while the aberration diagrams in the lower three parts correspond to an image blur compensation state at a telephoto limit where the sub lens unit (first sub lens unit or second sub lens unit) for image blur compensation included in the fourth lens unit G4 moves by a predetermined amount in a direction perpendicular to the optical axis. Among the lateral aberration diagrams of a basic state, the upper part shows the lateral aberration at an image point of 70% of the maximum image height, the middle part shows the lateral aberration at the axial image point, and the lower part shows the lateral aberration at an image point of -70% of the maximum image height. Among the lateral aberration diagrams of an image blur compensation state, the upper part shows the lateral aberration at an image point of 70% of the maximum image height, the middle part shows the lateral aberration at the axial image point, and the lower part shows the lateral aberration at an image point of -70% of the maximum image height. Further, in each lateral aberration diagram, the horizontal axis indicates the distance from the principal ray on the pupil surface, and the solid line, the short dash line, and the long dash line indicate the characteristics to the d-line, the F-line, and the C-line, respectively. In each lateral aberration diagram, the meridional image plane is adopted as the plane containing the optical axis of the first lens unit G1.

Here, in the zoom lens system according to each numerical example, the amount (Y_T (mm)) of movement of the compensation lens unit in a direction perpendicular to the optical axis in an image blur compensation state at a telephoto limit is as follows.

TABLE 1

(Amount of movement of compensation lens unit)	
Numerical Example	Y_T
1	0.307
2	0.316
3	0.135
4	0.308
5	0.314

Numerical Example 1

The zoom lens system of Numerical Example 1 corresponds to Embodiment 1 shown in FIG. 1. Data of the zoom lens system according to Numerical Example 1, i.e., the surface data, the aspheric surface data, the various data, the lens element data, the zoom lens unit data, and the zoom lens unit magnification are shown in Table 2, Table 3, Table 4, Table 5, Table 6, and Table 7, respectively.

TABLE 2

(Surface data)				
Surface number	r	d	nd	vd
Object surface	∞			
1	93.29160	1.49730	1.84666	23.8
2	50.82680	7.10180	1.49700	81.6

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TABLE 2-continued

(Surface data)				
Surface number	r	d	nd	vd
3	-850.01520	0.15000		
4	47.79330	5.18430	1.71300	53.9
5	149.47070	Variable		
6*	76.05160	0.10000	1.51358	51.6
7	53.79460	1.10000	1.88300	40.8
8	11.90020	6.30730		
9	-20.07120	0.83030	1.88300	40.8
10	-51.30870	0.87050		
11	31.52170	3.39400	1.94595	18.0
12	-51.59310	Variable		
13*	-19.66880	1.20040	1.80470	41.0
14*	129.88760	Variable		
15(Diaphragm)	∞	0.84560		
16*	23.65630	3.02980	1.69350	53.2
17*	-55.43650	2.59200		
18	15.08640	3.25030	1.71300	53.9
19	-200.75790	0.81020	2.00069	25.5
20	15.26070	1.91050		
21	31.27490	5.91480	1.59201	67.0
22*	-20.38770	0.89910		
23	88.68500	2.96870	1.80518	25.5
24	-13.73040	0.80000	1.83481	42.7
25	16.65510	2.35020		
26	23.27780	4.19350	1.49700	81.6
27	-14.99240	0.80000	1.83481	42.7
28	-57.80160	1.35890		
29	-14.16000	0.80000	1.72916	54.7
30	-26.58250	0.10000		
31	32.36170	3.20070	1.51680	64.2
32	-81.55460	Variable		
33	∞	4.20000	1.51680	64.2
34	∞	BF		
image surface	∞			

TABLE 3

(Aspheric surface data)	
Sur-face No.	Parameters
6	K = -9.51780E-01, A4 = 2.71746E-05, A6 = -1.19865E-08, A8 = -8.37911E-10, A10 = 5.57759E-12, A12 = -1.15782E-14
13	K = 0.00000E+00, A4 = -3.91729E-05, A6 = 1.79189E-06, A8 = -3.13080E-08, A10 = 1.39737E-10, A12 = 2.27477E-12
14	K = -1.79163E-01, A4 = -4.45555E-05, A6 = 2.19191E-06, A8 = -5.22554E-08, A10 = 5.17499E-10, A12 = -1.04173E-13
16	K = 0.00000E+00, A4 = -1.12821E-05, A6 = 1.40905E-07, A8 = -2.71306E-09, A10 = -7.19478E-11, A12 = -7.19829E-15
17	K = 0.00000E+00, A4 = 2.44778E-05, A6 = -3.84078E-08, A8 = 1.18435E-09, A10 = -1.10289E-10, A12 = 7.33811E-15
22	K = 0.00000E+00, A4 = 1.81139E-05, A6 = -5.84158E-08, A8 = 6.50501E-09, A10 = -6.84134E-11, A12 = 0.00000E+00

TABLE 4

(Various data)			
Zooming ratio 9.33675			
	Wide	Middle	Telephoto
Focal length	14.4919	44.3151	135.3070
F-number	4.00318	5.40622	5.99766
View angle	39.8611	13.7123	4.5845
Image height	10.8150	10.8150	10.8150
Overall length of lens system	101.9455	132.7027	162.8905
BF	2.80549	2.83204	2.87020
d5	0.6596	22.5410	41.6141
d12	2.8371	3.0868	6.1035

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TABLE 4-continued

(Various data)			
Zooming ratio 9.33675			
	Wide	Middle	Telephoto
d14	18.4343	8.8238	2.7427
d32	9.4488	27.6589	41.7998
Entrance pupil position	25.3181	78.7228	223.8111
Exit pupil position	-37.3774	-55.5875	-69.7284
Front principal point position	34.5835	89.4220	106.9372
Back principal point position	87.4536	88.3877	27.5835

TABLE 5

(Lens element data)		
Unit	Initial surface No.	Focal length
1	1	-134.0520
2	2	96.7509
3	4	96.4914
4	6	-16.6778
5	9	-37.8072
6	11	21.1040
7	13	-21.1522
8	16	24.2899
9	18	19.8043
10	19	-14.1462
11	21	21.7746
12	23	14.9598
13	24	-8.9085
14	26	19.0411
15	27	-24.4565
16	29	-42.7154
17	31	45.2638

TABLE 6

(Zoom lens unit data)					
Unit	Initial surface No.	Focal length	Length of lens unit	Front principal point position	Back principal point position
1	1	76.72300	13.93340	3.26962	8.46360
2	6	-46.93302	12.60210	-10.83666	-15.28913
3	13	-21.15218	1.20040	0.08717	0.62478
4	15	19.37772	35.82430	0.10418	10.76940

TABLE 7

(Zoom lens unit magnification)				
Unit	Initial surface No.	Wide	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	-1.36049	-3.72016	7.26826
3	13	0.12997	0.07727	-0.08852
4	15	-1.06826	-2.00938	-2.74110

Numerical Example 2

The zoom lens system of Numerical Example 2 corresponds to Embodiment 2 shown in FIG. 4. Data of the zoom lens system of Numerical Example 2, i.e., the surface data, the aspheric surface data, the various data, the lens element data, the zoom lens unit data, and the zoom lens unit magnification are shown in Tables 8, 9, 10, 11, 12, and 13, respectively.

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TABLE 8

(Surface data)				
Surface number	r	d	nd	vd
5	Object surface			
1	92.44320	1.50040	1.84666	23.8
2	50.47000	6.96430	1.49700	81.6
3	-847.86000	0.15000		
4	47.25220	5.18030	1.71300	53.9
10	5	145.99490	Variable	
6*	76.11200	0.10120	1.51358	51.6
7	53.78650	1.10000	1.88300	40.8
8	11.89720	6.31220		
9	-19.99880	0.83260	1.88300	40.8
10	-51.23580	0.87230		
15	11	31.55930	3.41140	1.94595
12	-51.41040	Variable		
13*	-19.63500	1.20060	1.80470	41.0
14*	130.38440	Variable		
15(Diaphragm)	∞	0.84590		
16*	23.66010	3.04770	1.69350	53.2
17*	-55.50020	2.53870		
20	18	15.07960	3.25040	1.71300
19	-200.13220	0.81020	2.00069	25.5
20	15.26060	1.91230		
21	31.28720	5.87150	1.59201	67.0
22*	-20.38280	0.89910		
23	88.69790	2.96860	1.80518	25.5
25	24	-13.74920	0.80050	1.83481
25	25	16.65470	2.35520	
26	23.28540	4.19220	1.49700	81.6
27	-15.00380	0.80660	1.83481	42.7
28	-57.73780	1.34160		
29	-14.16980	0.82280	1.72916	54.7
30	30	-26.59680	0.14240	
31	32.16560	3.16330	1.51680	64.2
32	-83.11460	Variable		
33	∞	4.20000	1.51680	64.2
34	∞	BF		
35	Image surface			
	∞			

TABLE 9

(Aspherical data)	
Sur-face No.	Parameters
40	
6	K = -8.65420E-01, A4 = 2.71985E-05, A6 = -1.27416E-08, A8 = -8.47671E-10, A10 = 5.59117E-12, A12 = -1.03453E-14
13	K = 0.00000E+00, A4 = -3.92219E-05, A6 = 1.79165E-06, A8 = -3.13018E-08, A10 = 1.39699E-10, A12 = 2.24266E-12
14	K = 5.23028E-01, A4 = -4.45154E-05, A6 = 2.19210E-06, A8 = -5.22781E-08, A10 = 5.16605E-10, A12 = -1.29893E-13
16	K = 0.00000E+00, A4 = -1.12931E-05, A6 = 1.40885E-07, A8 = -2.71412E-09, A10 = -7.20168E-11, A12 = -9.67929E-15
17	K = 0.00000E+00, A4 = 2.44916E-05, A6 = -3.83424E-08, A8 = 1.18545E-09, A10 = -1.10236E-10, A12 = 9.17521E-15
22	K = 4.76603E-05, A4 = 1.81709E-05, A6 = -5.78282E-08, A8 = 6.49528E-09, A10 = -6.93375E-11, A12 = 0.00000E+00
55	

TABLE 10

(Various data)			
Zooming ratio 9.35820			
	Wide	Middle	Telephoto
Focal length	14.4939	44.3129	135.6373
F-number	4.00335	5.40554	5.99765
View angle	39.9177	13.7265	4.5757
Image height	10.8150	10.8150	10.8150
Overall length of lens system	101.6672	132.4129	161.5468

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TABLE 10-continued

(Various data) Zooming ratio 9.35820			
	Wide	Middle	Telephoto
BF	2.80409	2.82823	2.86170
d5	0.6595	22.4493	41.6494
d12	2.6575	3.0940	6.3380
d14	18.4611	8.8422	2.7298
d32	9.4907	27.6049	40.3736
Entrance pupil position	25.1796	78.8630	230.4632
Exit pupil position	-37.4743	-55.5885	-68.3572
Front principal point position	34.4580	89.5616	107.7774
Back principal point position	87.1732	88.1000	25.9095

TABLE 11

(Lens element data)		
Unit	Initial surface No.	Focal length
1	1	-133.4756
2	2	96.0920
3	4	95.8923
4	6	-16.6715
5	9	-37.6192
6	11	21.0941
7	13	-21.1314
8	16	24.3029
9	18	19.7920
10	19	-14.1429
11	21	21.7676
12	23	14.9778
13	24	-8.9151
14	26	19.0518
15	27	-24.4932
16	29	-42.7860
17	31	45.2974

TABLE 12

(Zoom lens unit data)					
Unit	Initial surface No.	Focal length	Length of lens unit	Front principal point position	Back principal point position
1	1	76.12978	13.79500	3.16804	8.32000
2	6	-46.72192	12.62970	-10.78714	-15.22577
3	13	-21.13139	1.20060	0.08676	0.62446
4	15	19.40387	35.76900	0.15790	10.71360

TABLE 13

(Zoom lens unit magnification)				
Unit	Initial surface No.	Wide	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	-1.37173	-3.80760	6.74257
3	13	0.13000	0.07635	-0.09926
4	15	-1.06759	-2.00237	-2.66214

Numerical Example 3

The zoom lens system of Numerical Example 3 corresponds to Embodiment 3 shown in FIG. 7. Data of the zoom lens system of Numerical Example 3, i.e., the surface data, the aspheric surface data, the various data, the lens element data,

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the zoom lens unit data, and the zoom lens unit magnification are shown in Tables 14, 15, 16, 17, 18, and 19.

TABLE 14

(Surface data)				
Surface number	r	d	nd	vd
Object surface	∞			
1	92.18470	1.50890	1.84666	23.8
2	50.59720	7.14140	1.49700	81.6
3	-966.46410	0.15000		
4	47.41520	5.21930	1.71300	53.9
5	147.10900	Variable		
6*	76.06950	0.10000	1.51358	51.6
7	53.68590	1.10000	1.88300	40.8
8	11.89330	6.30890		
9	-20.09130	0.82990	1.88300	40.8
10	-51.39420	0.86980		
11	31.43820	3.39610	1.94595	18.0
12	-51.92400	Variable		
13*	-19.67220	1.20030	1.80470	41.0
14*	130.03760	Variable		
15 (Diaphragm)	∞	0.84510		
16*	23.65970	3.08600	1.69350	53.2
17*	-55.55620	2.52620		
18	15.07550	3.25020	1.71300	53.9
19	-200.60280	0.81020	2.00069	25.5
20	15.26000	1.91520		
21	31.28380	5.89510	1.59201	67.0
22*	-20.38310	0.89970		
23	88.64240	2.96970	1.80518	25.5
24	-13.75430	0.80000	1.83481	42.7
25	16.65230	2.34540		
26	23.28500	4.18950	1.49700	81.6
27	-14.99040	0.80000	1.83481	42.7
28	-57.73810	1.34500		
29	-14.15720	0.80000	1.72916	54.7
30	-26.59940	0.12110		
31	32.21740	3.16040	1.51680	64.2
32	-82.24800	Variable		
33	∞	4.20000	1.51680	64.2
34	∞	BF		
Image surface	∞			

TABLE 15

(Aspheric surface data)	
Sur-face No.	Parameters
6	K = -9.10525E-01, A4 = 2.71853E-05, A6 = -1.17499E-08, A8 = -8.46191E-10, A10 = 5.58176E-12, A12 = -1.05149E-14
13	K = 0.00000E+00, A4 = -3.91920E-05, A6 = 1.79159E-06, A8 = -3.13204E-08, A10 = 1.39427E-10, A12 = 2.21441E-12
14	K = 2.72517E-01, A4 = -4.45295E-05, A6 = 2.19143E-06, A8 = -5.22877E-08, A10 = 5.16656E-10, A12 = -5.67168E-14
16	K = 0.00000E+00, A4 = -1.12941E-05, A6 = 1.40911E-07, A8 = -2.71164E-09, A10 = -7.19359E-11, A12 = -5.77241E-15
17	K = 0.00000E+00, A4 = 2.44934E-05, A6 = -3.84036E-08, A8 = 1.18226E-09, A10 = -1.10332E-10, A12 = 5.60567E-15
22	K = 0.00000E+00, A4 = 1.81820E-05, A6 = -5.77336E-08, A8 = 6.49279E-09, A10 = -6.93404E-11, A12 = 0.00000E+00

TABLE 16

(Various data) Zooming ratio 9.33034			
	Wide	Middle	Telephoto
Focal length	14.5015	44.3144	135.3042
F-number	4.00344	5.40547	5.99782
View angle	39.8346	13.7288	4.5866

TABLE 16-continued

(Various data)			
Zooming ratio 9.33034			
	Wide	Middle	Telephoto
Image height	10.8150	10.8150	10.8150
Overall length of lens system	101.9638	132.5433	161.6026
BF	2.80190	2.83011	2.85362
d5	0.6873	22.4396	41.7186
d12	2.7417	3.0466	6.0472
d14	18.4749	8.8416	2.7452
d32	9.4746	27.6020	40.4546
Entrance pupil position	25.4494	78.8584	228.9072
Exit pupil position	-37.3528	-55.4802	-68.3328
Front principal point position	34.7139	89.4949	107.0383
Back principal point position	87.4623	88.2289	26.2984

TABLE 17

(Lens element data)		
Unit	Initial surface No.	Focal length
1	1	-134.7090
2	2	96.9672
3	4	96.0367
4	6	-16.6695
5	9	-37.8277
6	11	21.1192
7	13	-21.1586
8	16	24.3146
9	18	19.7900
10	19	-14.1448
11	21	21.7708
12	23	14.9815
13	24	-8.9164
14	26	19.0411
15	27	-24.4618
16	29	-42.6645
17	31	45.2195

TABLE 18

(Zoom lens unit data)					
Unit	Initial surface No.	Focal length	Length of lens unit	Front principal point position	Back principal point position
1	1	76.41416	14.01960	3.24460	8.47258
2	6	-46.76258	12.60470	-10.77426	-15.18802
3	13	-21.15864	1.20030	0.08708	0.62466
4	15	19.38243	35.75880	0.11636	10.76666

TABLE 19

(Zoom lens unit magnification)				
Unit	Initial surface No.	Wide	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	-1.36767	-3.75928	6.83686
3	13	0.13021	0.07704	-0.09712
4	15	-1.06567	-2.00237	-2.66669

Numerical Example 4

The zoom lens system of Numerical Example 4 corresponds to Embodiment 4 shown in FIG. 10. Data of the zoom lens system of Numerical Example 4, i.e., the surface data, the aspheric surface data, the various data, the lens element data, the zoom lens unit data, and the zoom lens unit magnification are shown in Tables 20, 21, 22, 23, 24, and 25, respectively.

TABLE 20

(surface data)				
Surface number	r	d	nd	vd
Object surface	∞			
1	90.30820	1.93190	1.84666	23.8
2	50.87660	7.33030	1.49700	81.6
3	-922.88540	0.15000		
4	48.34930	4.89480	1.71700	47.9
5	147.06100	Variable		
6*	58.12980	1.20000	1.90681	21.2
7	11.31120	6.28100		
8	-19.38970	0.89450	1.88300	40.8
9	-64.19440	0.91900		
10	30.72250	3.72760	1.94595	18.0
11	-33.35260	Variable		
12*	-18.28890	1.20110	1.80420	46.5
13*	109.11350	Variable		
14(Diaphragm)	∞	0.80610		
15*	23.54260	2.43820	1.69350	53.2
16*	-52.76110	5.60730		
17	15.34600	3.22520	1.71300	53.9
18	-197.48210	0.80880	2.00069	25.5
19	15.25880	1.47090		
20	26.90540	3.11630	1.59201	67.0
21*	-22.34970	0.87140		
22	97.11210	3.05020	1.80518	25.5
23	-15.86630	0.80000	1.83481	42.7
24	16.64980	1.87130		
25	23.47560	4.44630	1.49700	81.6
26	-14.64800	0.80000	1.83481	42.7
27	-60.20220	1.24930		
28	-17.34570	0.80000	1.72916	54.7
29	-39.86110	0.28520		
30	33.25040	2.68470	1.51680	64.2
31	-73.57350	Variable		
32	∞	4.20000	1.51680	64.2
33	∞	BF		
Image surface	∞			

TABLE 21

(aspherical data)	
Surface No.	Parameters
6	K = -1.96414E+01, A4 = 2.17865E-05, A6 = -7.11149E-08, A8 = -4.34378E-10, A10 = 4.69717E-12, A12 = -1.54970E-14
12	K = 0.00000E+00, A4 = -2.79093E-05, A6 = 2.00080E-06, A8 = -2.37691E-08, A10 = 1.26736E-11, A12 = 9.26223E-13
13	K = 5.35969E+01, A4 = -4.04231E-05, A6 = 2.44155E-06, A8 = -5.15800E-08, A10 = 5.92811E-10, A12 = -2.81121E-12
15	K = 0.00000E+00, A4 = -6.06935E-06, A6 = 3.73242E-08, A8 = -3.05202E-09, A10 = -7.46214E-11, A12 = -3.43954E-13
16	K = 0.00000E+00, A4 = 2.56389E-05, A6 = -7.24066E-08, A8 = -4.48824E-10, A10 = -1.28984E-10, A12 = 6.18123E-15
21	K = 0.00000E+00, A4 = 2.54758E-05, A6 = 9.61906E-08, A8 = 7.43701E-10, A10 = -3.39306E-13, A12 = 0.00000E+00

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TABLE 22

(various data)			
Zooming ratio 9.50927			
	Wide	Middle	Telephoto
Focal length	14.5133	44.3163	138.0113
F-number	4.05105	5.51642	6.29179
View angle	40.2948	13.6070	4.4736
Image height	10.8150	10.8150	10.8150
Overall length of lens system	101.9105	133.8869	163.2443
BF	2.79643	2.82858	2.86373
d5	0.6599	22.4056	41.2644
d11	3.5868	5.1902	7.2600
d13	18.1884	8.8136	2.7095
d31	9.6176	27.5875	42.0853
Entrance pupil position	25.5492	80.6266	224.4799
Exit pupil position	-36.1526	-54.1225	-68.6203
Front principal point position	34.6545	90.4583	96.0385
Back principal point position	87.3972	89.5705	25.2330

TABLE 23

(lens element data)		
Unit	Initial surface No.	Focal length
1	1	-140.7850
2	2	97.2626
3	4	98.4231
4	6	-15.6783
5	8	-31.7592
6	10	17.3976
7	12	-19.3956
8	15	23.7846
9	17	20.0980
10	18	-14.1277
11	20	21.1187
12	22	17.1444
13	23	-9.6242
14	25	18.8798
15	26	-23.3754
16	28	-42.7558
17	30	44.6955

TABLE 24

(Zoom lens unit data)					
Unit	Initial surface No.	Focal length	Length of lens unit	Front principal point position	Back principal point position
1	1	76.52671	14.30700	3.39343	8.72110
2	6	-81.54993	13.02210	-25.94425	-41.08891
3	12	-19.39560	1.20110	0.09517	0.63333
4	14	19.08890	34.33120	-0.71921	9.87207

TABLE 25

(zoom lens unit magnification)				
Unit	Initial surface No.	Wide	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	-5.55698	11.53388	3.14509
3	12	0.03170	-0.02486	-0.20618
4	14	-1.07671	-2.01978	-2.78111

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Numerical Example 5

The zoom lens system of Numerical Example 5 corresponds to Embodiment 5 shown in FIG. 13. Data of the zoom lens system of Numerical Example 5, i.e., the surface data, the aspheric surface data, the various data, the lens element data, the zoom lens unit data, and the zoom lens unit magnification are shown in Tables 26, 27, 28, 29, 30, and 31, respectively.

TABLE 26

(surface data)				
Surface number	r	d	nd	vd
Object surface	∞			
1	78.05430	1.50000	1.84666	23.8
2	47.86090	7.82000	1.49700	81.6
3	-2811.69830	0.15000		
4	45.22120	5.58000	1.58913	61.3
5	159.80500	Variable		
6*	76.22710	1.50000	1.80610	40.7
7	11.48720	6.49850		
8	-25.34440	0.80000	1.80420	46.5
9	-144.44850	0.27270		
10	26.87530	3.55000	1.94595	18.0
11	-79.37890	Variable		
12*	-22.52260	1.10000	1.80610	40.7
13*	111.65510	Variable		
14(Diaphragm)	∞	0.90030		
15*	15.72440	3.34000	1.69350	53.2
16*	-97.79480	0.53570		
17	15.91670	2.60000	1.69962	55.3
18	121.55860	0.70000	2.00069	25.5
19	13.58960	1.13010		
20	39.58830	3.88000	1.49700	81.6
21	-16.97330	1.56860		
22	271.67740	3.45000	1.84666	23.8
23	-14.95720	0.70000	1.83481	42.7
24	17.34190	2.52590		
25	52.65190	2.63000	1.49700	81.6
26	-63.47340	1.59420		
27	-14.34770	1.10000	1.80610	40.7
28*	-25.33540	0.15000		
29	21.81500	5.47000	1.49700	81.6
30	-19.40750	0.70000	1.77250	49.6
31	-49.40210	Variable		
32	∞	4.20000	1.51680	64.2
33	∞	BF		
Image surface	∞			

TABLE 27

(aspherical data)	
Surface No.	Parameters
6	K = 0.00000E+00, A4 = 1.29469E-05, A6 = -2.04795E-08, A8 = -2.69870E-10, A10 = 1.82078E-12, A12 = -4.05694E-15
12	K = 0.00000E+00, A4 = -5.27193E-05, A6 = 1.84470E-06, A8 = -2.69590E-08, A10 = 2.09790E-10, A12 = -3.43788E-13
13	K = 0.00000E+00, A4 = -4.85338E-05, A6 = 1.64899E-06, A8 = -2.62063E-08, A10 = 2.03012E-10, A12 = 0.00000E+00
15	K = 0.00000E+00, A4 = -1.30370E-06, A6 = 1.15937E-07, A8 = 1.23700E-09, A10 = 1.54415E-10, A12 = 0.00000E+00
16	K = 0.00000E+00, A4 = 7.66841E-05, A6 = 1.11210E-07, A8 = 2.03485E-09, A10 = 1.99005E-10, A12 = 0.00000E+00
28	K = 0.00000E+00, A4 = -1.11851E-07, A6 = 1.14428E-06, A8 = -5.01498E-08, A10 = 1.16520E-09, A12 = -1.00877E-11

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TABLE 28

(various data) Zooming ratio 9.27842			
	Wide	Middle	Telephoto
Focal length	14.5708	44.3848	135.1938
F-number	4.16329	4.96539	5.82732
View angle	38.9333	13.4967	4.5019
Image height	10.6150	10.6150	10.6150
Overall length of lens system	101.9979	130.1011	158.9982
BF	2.77797	2.84202	2.81725
d5	0.7000	21.5452	40.0030
d11	2.9897	3.4834	7.0416
d13	20.1533	9.3395	2.4926
d31	9.4309	26.9450	40.6978
Entrance pupil position	28.3323	81.6514	226.3810
Exit pupil position	-37.7892	-55.3033	-69.0561
Front principal point position	37.6696	92.1553	107.2749
Back principal point position	87.4271	85.7163	23.8044

TABLE 29

(lens element data)		
Unit	Initial surface No.	Focal length
1	1	-149.5413
2	2	94.7744
3	4	105.1546
4	6	-16.9542
5	8	-38.3360
6	10	21.5753
7	12	-23.1655
8	15	19.7714
9	17	25.9156
10	18	-15.3392
11	20	24.4603
12	22	16.8371
13	23	-9.5259
14	25	58.3449
15	27	-42.9602
16	29	21.6174
17	30	-41.8036

TABLE 30

(Zoom lens unit data)					
Unit	Initial surface No.	Focal length	Length of lens unit	Front principal point position	Back principal point position
1	1	76.52351	15.05000	3.15738	8.47428
2	6	-39.03253	12.62120	-6.65518	-7.89966
3	12	-23.16550	1.10000	0.10186	0.59503
4	14	20.03471	32.97480	0.72903	8.14210

TABLE 31

(zoom lens unit magnification)				
Unit	Initial surface No.	Wide	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	-1.05864	-2.43569	16.04584
3	12	0.18222	0.12772	-0.04318
4	14	-0.98708	-1.86446	-2.54968

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The following Table 32 show values corresponding to the individual conditions in the zoom lens systems of the respective numerical examples.

TABLE 32

(corresponding values to individual conditions: Numerical Examples 1 to 5)					
Condition	Numerical Example				
	1	2	3	4	5
(1) $f_{A4}/f_{A\alpha}$	0.86	0.86	0.86	0.87	0.79
(2) $f_{AOB}/f_{A\alpha}$	0.86	0.86	0.86	0.87	0.79
(3) $f_{AB}/f_{A\alpha}$	-1.22	-1.22	-1.22	-1.22	-1.14
(4) $f_{Am}/f_{A\alpha}$	4.03	4.00	4.02	4.38	2.75
(5) f_{Ac}/f_W	1.34	1.34	1.34	1.32	1.38
(6) $f_F/f_{A\alpha}$	-1.09	-1.09	-1.09	-1.02	-1.16
(7) $f_1 * (f_T/f_W)/\sqrt{(f_W * f_T)}$	16.19	16.07	16.10	16.27	16.01
(8) $f_2 * (f_T/f_W)/\sqrt{(f_W * f_T)}$	-9.90	-9.86	-9.86	-17.34	-8.16
(9) $\delta t_1/f_1$	0.79	0.79	0.78	0.80	0.74
(10) $\delta t_2/f_2$	-0.42	-0.40	-0.40	-0.25	-0.45
(11) $\delta t_3/f_3$	-0.79	-0.72	-0.72	-0.88	-0.59
(12) $\delta t_4/f_4$	1.67	1.59	1.60	1.70	1.56
(13) β_{2T}/β_{2W}	-5.34	-4.91	-5.00	-0.57	-15.15
(14) β_{3T}/β_{3W}	-0.68	-0.76	-0.75	-6.44	-0.24
(15) β_{4T}/β_{4W}	2.57	2.49	2.50	2.58	2.58
(16) $f_3 * \beta_{3W} * \beta_{3W}/(\delta_{53} * f_T/f_W)$	6.21	6.09	5.99	-0.09	5.33
(17) $DIS_W * f_T/f_W$	-1.02	-1.03	-1.02	-1.14	-0.93
(18) nd_2	1.904	1.904	1.904	1.912	1.852

The zoom lens system according to the present invention is applicable to a digital input device such as a digital still camera, a digital video camera, a mobile telephone, a PDA (Personal Digital Assistance), a surveillance camera in a surveillance system, a Web camera or a vehicle-mounted camera. In particular, the present zoom lens system is suitable for an imaging device in a digital still camera, a digital video camera or the like that requires high image quality.

Details of the present invention have been described above. However, the above-mentioned description is completely illustrative from every point of view, and does not limit the scope of the present invention. Obviously, various improvements and modifications can be performed without departing from the scope of the present invention.

What is claimed is:

1. A zoom lens system, in order from an object side to an image side, comprising:

a first lens unit having positive optical power;
a second lens unit having negative optical power;
a third lens unit having negative optical power; and
a fourth lens unit having positive optical power and being arranged closest to the image side, wherein

at the time of zooming, at least the first lens unit moves from a wide-angle limit to a telephoto limit,
the fourth lens unit includes a first sub lens unit having positive optical power and a second sub lens unit having negative optical power, the second sub lens unit being arranged at the image side relative to the first sub lens unit,

at the time of compensating image blur caused by vibration applied to the zoom lens system, the first sub lens unit or the second sub lens unit moves in a direction perpendicular to the optical axis, and

the following condition is satisfied:

$$0.5 < \delta t_1/f_1 < 1.1$$

(9)

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where,

δt_1 is an amount of movement of the first lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_1 is a focal length of the first lens unit.

2. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$12 < f_1 * (f_T / f_W) / \sqrt{(f_W * f_T)} < 27 \quad (7)$$

where,

f_1 is a focal length of the first lens unit,

f_T is a focal length of an entire system at a telephoto limit, and

f_W is a focal length of the entire system at a wide-angle limit.

3. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-20 < f_2 * (f_T / f_W) / \sqrt{(f_W * f_T)} < -6 \quad (8)$$

where,

f_2 is a focal length of the second lens unit,

f_T is a focal length of an entire system at a telephoto limit, and

f_W is a focal length of the entire system at a wide-angle limit.

4. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-0.7 < \delta t_2 / f_2 < -0.2 \quad (10)$$

where,

δt_2 is an amount of movement of the second lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_2 is a focal length of the second lens unit.

5. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-1.2 < \delta t_3 / f_3 < -0.4 \quad (11)$$

where,

δt_3 is an amount of movement of the third lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_3 is a focal length of the third lens unit.

6. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$1.2 < \delta t_4 / f_4 < 2.0 \quad (12)$$

where,

δt_4 is an amount of movement of the fourth lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_4 is a focal length of the fourth lens unit.

7. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-25 < \beta_{2T} / \beta_{2W} < 34 \quad (13)$$

where,

β_{2T} is paraxial imaging magnification of the second lens unit at a telephoto limit, and

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β_{2W} is paraxial imaging magnification of the second lens unit at a wide-angle limit.

8. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-8 < \beta_{3T} / \beta_{3W} < 0.2 \quad (14)$$

where,

β_{3T} is paraxial imaging magnification of the third lens unit at a telephoto limit, and

β_{3W} is paraxial imaging magnification of the third lens unit at a wide-angle limit.

9. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$2 < \beta_{4T} / \beta_{4W} < 3.2 \quad (15)$$

where,

β_{4T} is paraxial imaging magnification of the fourth lens unit at a telephoto limit, and

β_{4W} is paraxial imaging magnification of the fourth lens unit at a wide-angle limit.

10. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-0.3 < f_F * \beta_{FW} * \beta_{FW} / (\delta S_F * f_T / f_W) < 7.0 \quad (6)$$

where,

f_F is a focal length of a focusing lens unit,

β_{FW} is paraxial imaging magnification of the focusing lens unit at a wide-angle limit,

δS_F is an amount of distortion of an aspheric surface at a height of $0.5 * f_W * \tan \omega_W$ from an optical axis, the aspheric surface being arranged closest to the object side in the focusing lens unit,

f_T is a focal length of an entire system at a telephoto limit,

f_W is a focal length of the entire system at a wide-angle limit, and

ω_W is a half view angle at a wide-angle limit.

11. The zoom lens system as claimed in claim 1, satisfying the following condition:

$$-1.7 \text{ mm} < \text{DIS}_W * f_T / f_W < -0.5 \text{ mm} \quad (17)$$

where,

DIS_W is an amount of distortion of a maximum image height at a wide-angle limit,

f_T is a focal length of an entire system at a telephoto limit, and

f_W is a focal length of the entire system at a wide-angle limit.

12. An interchangeable lens apparatus, comprising:

a zoom lens system; and

a mount section detachably connected to a camera body that includes an image sensor which receives an optical image formed by the zoom lens system thereby to convert the optical image to an electrical image signal, wherein

the zoom lens system, in order from an object side to an image side, includes:

a first lens unit having positive optical power;

a second lens unit having negative optical power;

a third lens unit having negative optical power; and

a fourth lens unit having positive optical power and being arranged closest to the image side, wherein

at the time of zooming, at least the first lens unit moves from a wide-angle limit to a telephoto limit,

the fourth lens unit includes a first sub lens unit having positive optical power and a second sub lens unit having negative optical power, the second sub lens unit being arranged at the image side relative to the first sub lens unit,

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at the time of compensating image blur caused by vibration applied to the zoom lens system, the first sub lens unit or the second sub lens unit moves in a direction perpendicular to the optical axis, and the following condition is satisfied:

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$$0.5 < \delta t_1 / f_1 < 1.1 \tag{9}$$

where,

δt_1 is an amount of movement of the first lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and

f_1 is a focal length of the first lens unit.

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13. A camera system, comprising:

an interchangeable lens apparatus that includes a zoom lens system; and

a camera body which is connected to the interchangeable lens apparatus via a camera mount section in an attachable and removable manner and includes an image sensor which receives an optical image formed by the zoom lens system thereby to convert the optical image to an electrical image signal, wherein

the zoom lens system, in order from an object side to an image side, includes:

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a first lens unit having positive optical power; a second lens unit having negative optical power; a third lens unit having negative optical power; and a fourth lens unit having positive optical power and being arranged closest to the image side, wherein at the time of zooming, at least the first lens unit moves from a wide-angle limit to a telephoto limit, the fourth lens unit includes a first sub lens unit having positive optical power and a second sub lens unit having negative optical power, the second sub lens unit being arranged at the image side relative to the first sub lens unit,

at the time of compensating image blur caused by vibration applied to the zoom lens system, the first sub lens unit or the second sub lens unit moves in a direction perpendicular to the optical axis, and the following condition is satisfied:

(9)

$$0.5 < \delta t_1 / f_1 < 1.1$$

where,

δt_1 is an amount of movement of the first lens unit from a wide-angle limit to a telephoto limit (where, the position of the wide-angle limit is set as a reference, and expansion to the object side from the reference position is regarded as a positive value), and f_1 is a focal length of the first lens unit.

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